Tendency of Driving to the Basket Is Associated With Increased Risk of Anterior Cruciate Ligament Tears in National Basketball Association Players

A Cohort Study

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Background: Driving to the basket in basketball involves acceleration, deceleration, and lateral movements, which may expose players to increased anterior cruciate ligament (ACL) injury risk. It is unknown whether players who heavily rely on driving have decreased performance on returning to play after ACL reconstruction (ACLR).

Hypothesis: Players with a greater tendency to drive to the basket would be more likely to tear their ACL versus noninjured controls and would experience decreased performance when returning to play after ACLR.

Study Design: Case-control study; Level of evidence, 3.

Methods: Season-level performance statistics and ACL injuries were aggregated for National Basketball Association (NBA) seasons between 1980 and 2017 from publicly available sources. Players' tendency to drive was calculated using 49 common season-level performance metrics. Each ACL-injured player was matched with 2 noninjured control players by age, league experience, and style of play metrics. Points, playing minutes, driving, and 3-point shooting tendencies were compared between players with ACL injuries and matched controls. Independent-samples *t* test was utilized for comparisons.

Results: Of 86 players with a total of 96 ACL tears identified in the NBA, 50 players were included in the final analysis. Players who experienced an ACL tear had a higher career-average drive tendency than controls ($P = .047$). Players with career-average drive tendency ≥ 1 standard deviation above the mean were more likely to tear their ACL than players with drive tendency <1 standard deviation (5.2% vs 2.7%; $P = .026$). There was no significant difference in total postinjury career points ($P = .164$) or career minutes ($P = .237$) between cases and controls. There was also no significant change in drive tendency ($P = .152$) or 3-point shooting tendency ($P = .508$) after return to sport compared with controls.

Conclusion: NBA players with increased drive tendency were more likely to tear their ACL. However, players who were able to return after ACLR did not underperform compared with controls and did not alter their style of play compared with the normal changes seen with age. This information can be used to target players with certain playing styles for ACL injury prevention programs.

Keywords: ACL; return to sport; basketball; NBA

Knee injuries are common in the National Basketball Association (NBA), accounting for 13.8% of all reportable injuries and causing the most amount of time lost per injury.[3,16] The rate of anterior cruciate ligament (ACL) tears specifically is relatively high, being reported in up to 2.7% of players.[3] Although the rate of return to sport (RTS) is high after ACL reconstruction (ACLR) in NBA players—reported to be between 84% and 89%[5,7,13,14] across major professional sports—NBA players have the longest average time to RTS after ACLR,[11] with reported means of up to 9.8 months.[14] This longer time to RTS is likely because of the explosiveness, change of direction, and heavy axial loading required in basketball, all of which put biomechanical strain on the ACL.[1,4,8-10] Previous reports looking at RTS performance in the NBA specifically have been mixed, with some investigations demonstrating no difference in post-ACLR performance compared with matched controls[3,5,11,12] and others showing decreased performance statistics and career longevity.[7,14,15]

Two fundamental aspects of basketball are driving the ball to the basket and long-range shooting. Driving involves lateral changes of direction and acceleration/deceleration movements, whereas long-range shooting features primarily vertical explosive movement. The biomechanical demands of these 2 scoring approaches may affect risk of ACL injury[1,4,8,9] and subsequent RTS and post-ACLR performance.

Prior investigations have found no differences in ACL injury or performance outcomes across player positions in the NBA[5] in contrast to other major professional sports like the National Football League.[2] It is possible that this is due to a failure of traditionally defined basketball positions to accurately capture the differences in playing style observed across players that are most relevant for injury, RTS, and performance analyses. Statistical pattern recognition methods may provide more relevant representations of playing style (and therefore injury risk) compared with the traditional point/shooting guard, small/power forward, and center position designations utilized previously. This may then allow us to consider a wide diversity of performance metrics when conducting case-control matching. They also allow us to obtain a player's drive tendency, a measure of how frequently a player drives the ball independent of how much playing time they receive and how often they have the ball. This allows us to isolate the ACL injury risk of driving from the ACL injury risk of playing basketball in general.

Our purpose was to determine whether those players with increased drive tendency were more likely to sustain an ACL injury and whether this injury was associated with decreased performance after return to play in the NBA. We hypothesized that (1) players with higher drive tendency would be more likely to tear their ACL and (2) NBA players with ACL injuries would have inferior performance outcomes compared with controls, with players with a high drive tendency experiencing greater performance outcome decrements. We also examined whether (1) players with ACL injuries had lower reliance on 3-point shooting before injury versus the general NBA player population and (2) players relied more on 3-point shooting after sustaining an ACL injury.

METHODS

Overview

Public data were utilized for this study, and institutional review board approval was not sought. Common season-level performance statistics and ACL injury occurrences were aggregated from publicly available sources for all NBA players for every season between 1980 and 2017. Players' tendency to drive the ball was estimated from these statistics. Three-point shooting tendency was measured using the commonly available 3-point attempt rate (3PAr) statistic for each player-season. Differences in drive tendency and 3PAr were assessed between those who sustained an ACL injury and those who did not.

We performed case-control matching to investigate whether driving tendency and 3PAr were associated with RTS outcomes for ACL injury. The last full season before case players' ACL injuries was matched at a ratio of 1 case to 2 controls with similar seasons of control players without a history of ACL injury. The association among case-control performance differences, case driving tendencies, and case 3PAr was evaluated.

Data

Forty-nine common season-level performance statistics were obtained for player-seasons in the NBA between 1980 and the 2016-2017 season[5] (Table 1). Principal component analysis was used to consolidate these performance statistics into 18 new metrics that summarized each player-seasons' style of play (style of play metrics).

All NBA players who sustained an ACL tear were identified from publicly available injury reports and press releases. All players who started their career before 1980 were removed to exclude careers that occurred before the introduction of the 3-point line. All players who never averaged at least 5 minutes per game in any season of their career were excluded in order to focus analyses on those with significant recorded statistics. Players were excluded from analyses if they sustained their injury before 1980, played in a league other than the NBA after their injury, sustained their injury in 2015 or later (and therefore did not have adequate opportunity to make a recorded return by 2017), sustained a previous ACL tear, or sustained their injury during their rookie year (and therefore lacked pre-injury performance data). A total of 96 ACL tears (86 players) were initially identified, with 50 players eventually being included for data analysis (Figure 1).

We then calculated players' tendency to drive in each season using their style of play metrics. We defined a player-season's "drive tendency" as the estimated normalized drives per minute after controlling for minutes played and utilization (with utilization defined as the sum of field

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TABLE 1
Comparisons in Baseline Performance Statistics Between the Index Season for the Cases (n = 50) and the Average
of the 2 Matched Seasons for the Controls (n = 100)[a]

No.	Statistic	P (Cases vs Controls)	No.	Statistic	P (Cases vs Controls)
1	Year	.914	26	Field goal attempts	.827
2	Age	.965	27	Field goal percentage	.730
3	Games	.299	28	3-point scores	.590
4	Minutes played	.786	29	3-point attempts	.715
5	Player efficiency rating	.283	30	3-point percentage	.408
6	True shot percentage	.385	31	2-point scores	.871
7	3-point attempt per field goal attempt	.848	32	2-point attempts	.922
8	Free throw rate	.119	33	2-point percentage	.784
9	Offensive rebound percentage	.906	34	Effective field goal percentage	.551
10	Defensive rebound percentage	.933	35	Free throw scores	.422
11	Total rebound percentage	.897	36	Free throw attempts	.318
12	Assist percentage	.769	37	Free throw percentage	.895
13	Steal percentage	.905	38	Offensive rebounds	.764
14	Block percentage	.752	39	Defensive rebounds	.651
15	Turnover percentage	.795	40	Total rebounds	.682
16	Usage percentage	.0595	41	Assists	.689
17	Offensive win shares	.764	42	Steals	.527
18	Defensive win shares	.427	43	Blocks	.070
19	Win shares	.596	44	Turnovers	.922
20	Win shares per 48 min	.431	45	Personal fouls	.943
21	Offensive box plus/minus	.769	46	Points	.632
22	Defensive box plus/minus	.220	47	Height (in)	.801
23	Box plus/minus	.800	48	Weight (lb)	.894
24	Value over replacement	.673	49	BMI	.761
25	Field goal scores	.692	50	Drive tendency	.869

[a]The first 49 statistics are common season-level performance statistics, while the last statistic is drive tendency. BMI, body mass index.

Figure 1. Application of inclusion criteria for anterior cruciate ligament (ACL)–injured players. Inclusion criteria were applied in order to focus analyses on tears for which performance data were available both before and after the tear. This allowed us to perform case-control matching with preinjury data and then assess postinjury performance. NBA, National Basketball Association.
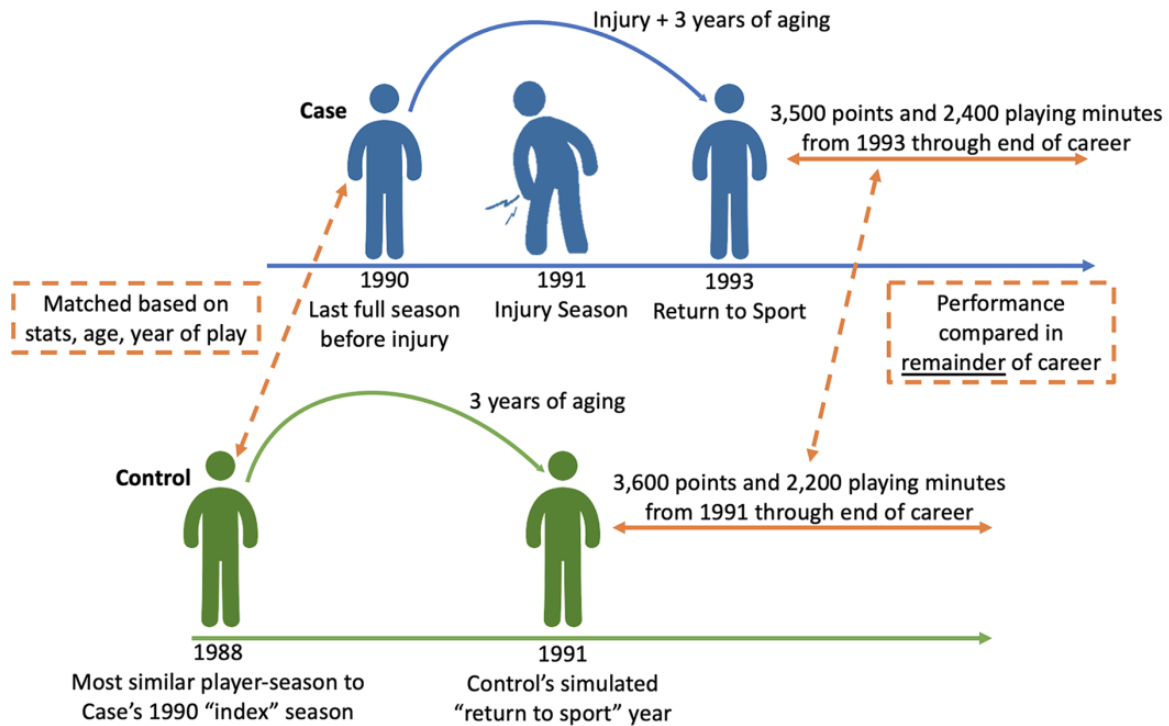
Figure 2. Case-control matching procedure with illustrative data. The last full season before anterior cruciate ligament reconstruction injury of the cases (ie, the index season) was matched with the 2 most similar player-seasons among all controls. The duration of time that the case player was out because of injury was added to the player-seasons of the matched controls to account for the effect of aging. Total playing minutes and points in the remainder of the case player's career were then compared with the minutes and points in their controls' remaining career.

goal attempts, free throw attempts, and turnovers). It captures how frequently a player drives the ball independent of how much playing time they receive and how often they have the ball. This allowed us to isolate the ACL injury risk of driving from the ACL injury risk of playing basketball in general. An in-depth description of how drive tendency was calculated and validated can be found in the Appendix.

Case-Control Matching Procedure

To estimate the effect of ACL injury on performance, each ACL-injured player was matched with 2 control players. Controls were used to predict how players' careers would have proceeded had they not sustained injury. The last full season before injury (the index season) was used for matching. Player-seasons used as controls had to be within 1 year of age and within 5 seasons of play of their matched case player. The 2 eligible player-seasons with the most similar style of play metrics to the case index season were used as matched controls. Significant differences between cases and controls for each common performance metric were checked. The number of seasons missed because of injury was calculated for each player with ACLR who returned to the NBA. These players not only sustained an injury but also underwent aging during their subsequent missed playing season(s). Aging is known to have a strong effect on sports performance. To isolate the effect of ACLR on

performance, we had to account for the effect of age. We therefore applied the same amount of aging to controls. We did this by skipping ahead the same number of seasons in the controls' careers as was missed due to ALCR in their cases' careers. The remainder of cases' careers were then compared with the remainder of the "skipped ahead" controls' careers (Figure 2).

Association Between Driving Tendency and ACL Injury Outcomes

To evaluate the effect of driving tendency on the quality of players' return to the NBA, we calculated total minutes played and total points scored for all seasons from the return season to the end of players' careers ("outcome metrics") for cases and controls. We took the difference between each case's outcome metrics and the average of their controls' outcome metrics to estimate the effect of ACL injury on performance. To measure the association between driving tendency and the effect of ACL injury on performance, we calculated the correlation between cases' career-average driving tendency and their case-control outcome metric difference.

A secondary hypothesis of this work was that ACLR would be associated with a decrease in drive tendency after return. To examine this, we calculated change in drive tendency observed with ACL injury for cases by averaging drive tendency for all seasons up through the index season,

averaging drive tendency for all seasons from the case return season onward, and then finding the difference. The same was done for controls using the control matching season and control return season. The change observed in cases was compared with the change observed in controls.

Association Between Shooting Adaptations and ACL Injury Outcomes

To evaluate shooting adaptions associated with ACLR, cases' average 3PAr in seasons before injury was compared with their average 3PAr after injury. The same was done for controls using the control matching season and control return season. The change observed in cases was compared with the change observed in controls.

Statistical Analysis

When comparing players' performance before injury versus after RTS, we used paired t tests. When comparing a players' performance with their 2 controls' performance, we used paired z tests. When comparing all cases to all players without ACL injury, we used independent-samples t tests. Statistical significance was set at $P < .05$. All analyses were done in the Python programming language (Version 3.8.0). Results were calculated with the SciPy (Version 1.6.2) and Scikit-learn (Version 0.24.1) libraries.

RESULTS

No significant differences were identified between the 50 cases (n = 50) and their matched controls (n = 100) across any of the 49 common season-level performance statistics or drive tendency for the season used for matching (Table 1).

Players who had an ACL injury while in the NBA were observed to have a significantly greater career-average drive tendency compared with controls ($P = .047$). When ACL injury rate was calculated across the driving tendency spectrum, higher ACL injury rates were observed at the highest levels of drive tendency (Figure 3). ACL injury rate is defined here as the percentage of players with a given range of drive tendency who experience an ACL injury while in the NBA. Players with career-average drive tendency ≥ 1 standard deviation (SD) above the mean had a significantly higher rate of ACL injury (5.2%) than those with career-average drive tendency <1 SD (2.7%) ($P = .026$; relative risk, 1.9) (Figure 3).

There was no significant difference in total postinjury career points between career-average driving tendency of ACL-injured players and their case-controls ($P = .164$) or minutes ($P = .237$). Driving tendency did not significantly decrease after ACLR in ACL-injured players ($P = .762$) and was not different from that of controls ($P = .152$). There was no difference in career-average 3PAr of ACL-injured players relative to other players ($P = .508$). Cases increased their average 3PAr for seasons after injury relative to seasons before injury by an average of 7% ($P < .001$). Controls showed a similar increase of 7.4% for their corresponding seasons ($P < .001$).
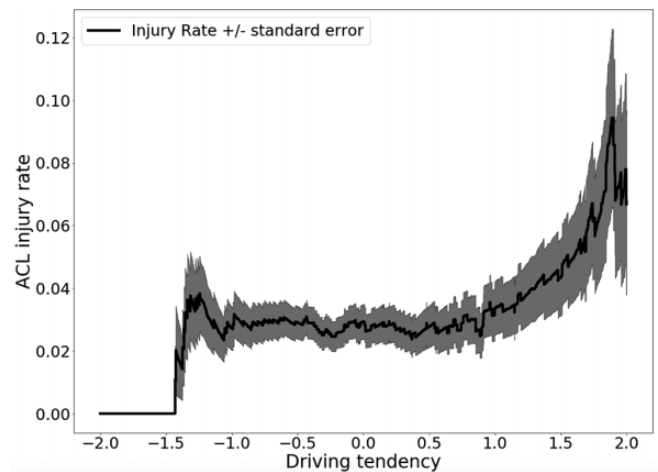

Figure 3. Estimated anterior cruciate ligament (ACL) injury rate versus driving tendency. The percentage of players who experienced an ACL injury while in the National Basketball Association was calculated using a moving average for this figure. Increasing ACL injury rates are observed for players with a drive tendency ≥ 1 SD above the mean. Gray shading represents standard error of the mean.

DISCUSSION

This study showed that players with career-average drive tendencies ≥ 1 SD above the mean have a significantly higher rate of ACL injury (5.2%) than those with career averages <1 SD (3.8%). However, for players who were able to make a significant return to the NBA, there was not a statistical difference in performance outcomes between players who had an ACL tear and controls and no difference specifically in the performance of players who had a higher tendency to drive to the basket versus controls. Changes in tendency to drive and to shoot 3-pointers after injury were comparable to the changes observed in age-matched controls over the injury time span. This implies that players able to return after ACLR do not consistently alter these aspects of their playing style as a result of injury.

Players with high drive tendency more likely rely on quick lateral movements and acceleration/deceleration movements, which are known mechanisms of ACL injury,[1,4,8-10] as compared with players who make more 3-point attempts. Previous literature has shown no difference in post-ACLR performance by traditional position type,[5] but drive tendency may be a better statistic to characterize player type. Identifying these at-risk athletes before injury is important, especially with elite athletes in the NBA, where an ACL injury to 1 key player can have large implications for team performance and player contracts. Teams should target ACL tear prevention programs to these players.[6]

Interestingly, there was no significant difference in total postinjury career points or career minutes between ACL-injured players and controls. This supports past findings of studies that used less objective or less holistic case-control matching procedures.[3,5,7,11,12,15] Previous literature has shown significantly decreased player performance in the year

after injury[5,7] but no decrease in performance in the long-term when compared with controls.[3,5,7] The exception to this is career longevity, with ACL-injured athletes having decreased career-average games played compared with controls.[3,5,7]

In this investigation, driving tendency was also not associated with case-control performance differences. In other words, players with ACLR with greater drive tendency did not fall farther behind the controls in terms of postreturn total points or minutes. The fact that ACLR does not significantly effect the performance or longevity of players who return to the NBA after injury is encouraging for players and health care providers.

Not only are players returning to play at similar performance levels after ACLR but also it does not appear that their style of play is significantly affected after injury. While injured players did tend to drive less than they did preinjury, this was not significantly different from the decrease in drive tendency observed among controls. There was a similar result with 3-point shooting tendencies, which significantly increased after injury-year, but again, this increase was not significantly different from the increase observed in controls over the same time period. The reasons for overall trends in decreasing drive tendency and increasing 3-point shooting tendencies with player age are likely multifactorial, but changes in these tendencies did not follow significantly different trajectories between players who returned to the NBA after injury and uninjured controls. Altering one's style of play in response to ACL injury may not be necessary or useful in elite basketball.

LIMITATIONS

Our model provides strong estimates for driving tendency when it is evaluated with modern players whose drives per minute are readily available. However, the retrospective review of games before 2013 in order to obtain historic drive per minute data has the potential to enhance model performance. While the data did show an association between drive tendency and ACL injury rate and we can hypothesize that this would be related to the biomechanical demands of driving, we did not identify a causal link. In our calculation of drive tendency, we controlled for minutes played and utilization, which allowed us to avoid confounding the ACL injury risk associated with driving with the risk that comes with many other aspects of playing basketball. However, it was not possible to control for every possible variable that might contribute to a player's risk. Our findings provide potential insight for targeted injury prevention, but they do not suggest the ability to predict which players will or will not sustain an ACL injury or offer specific risk reduction interventions.

Additionally, driving and 3-point shooting tendencies may be imperfect statistics to define specific styles of offensive play. Driving tendency is a convenient proxy for biomechanical variables like ACL strain that are difficult to measure directly for many players over many seasons. However, biomechanical analyses of the acts of driving and shooting and the strain on the ACL during these events would be useful future studies. We also did not have information on the specific action the player was performing during the ACL injury, for example, whether it was during a "driving" or "shooting" event. This would be important to determine if the insult to the knee is the act of driving or it is the cumulative wear and tear of repetitive driving that puts these athletes at higher risk of ACL tear. We also did not include players who returned to lower-level leagues (D-League or international league) but not the NBA, as complete statistics on these players were not available. This may serve to bias results toward certain players or playing styles. A final area of future research that we were not able to investigate using our small sample is the risk of ACL retear or contralateral injury in players who returned to play. This research was conducted using data from professional athletes, who may have different baseline physical characteristics and access to rehabilitation resources compared with the general population, so our conclusions may not be applicable for lower levels of competition.

CONCLUSION

Results indicated that NBA players with higher drive tendency are more likely to tear their ACL. However, for those players who were able to return to the NBA, there was no decline in points or minutes or alteration in style of play compared with controls. These data demonstrate that if players are able to RTS in the NBA after ACL injury, they can expect performance equal to noninjured controls.

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APPENDIX

Model Validation

Data on how often players drive to the basket in the National Basketball Association have only been tracked and publicly released since 2013. To obtain drive tendency for all player-seasons in our analysis, which spanned between 1980 and 2017, we used statistical pattern recognition techniques. We validated the accuracy of our model using ground-truth data from recent seasons. Below is the sequence of steps we used to create and validate our model for estimating drive tendency for all player-seasons.

1. Directly calculating drives per minute for recent seasons

The number of drives per season is a performance statistic that was introduced and made publicly available in 2013. We aggregated the 2013-2017 drives per season data for all player-seasons in that time range. This was then converted to drives per minute of playing time for each player-season using minutes-per-season data. Drives per minute for every player-season were then normalized by converting the data into Z scores such that 0 denoted average drives per minute and each unit denoted 1 SD from the average.

2. Estimating drives per minute for historic seasons

A linear regression model was then trained to estimate normalized drives per minute for player-seasons before 2013 (before driving data were made public). The training data for the model consisted of all 2013-2017 player-seasons. First, 49 common season-level performance statistics (Table 1) were consolidated into 18 new metrics that summarized each player-seasons' style of play using principal component analysis. The input to the model was these 18 new metrics for each player-season, and the output was the normalized drives per minute of the player-season.

3. Validation of the model for estimating normalized drives per minute

We used ground-truth drives per minute data from the 2013-2017 seasons to validate that our model produced
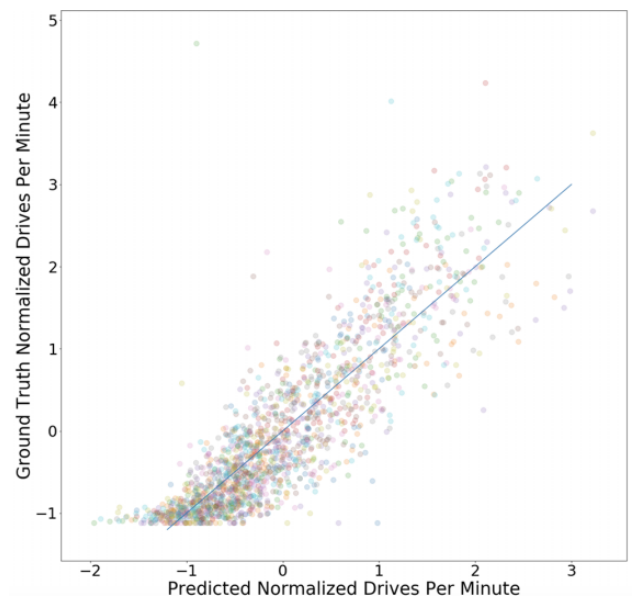

Figure A1. Tenfold cross-validation of the model used to estimate normalized drives per minute. Each point is a player-season. Each of the 10 colors denotes a different held-out set of player-seasons whose normalized drives per minute were estimated with the model. The solid line denotes where points would align if the model produced perfect estimates for all player-seasons.

accurate estimates of normalized drives per minute. Tenfold cross-validation was used to validate the ability of the model to accurately estimate drives per minute for players it had not seen during the model's training. All 2013-2017 player-seasons were divided into 10 roughly equal-sized groups. All seasons of a single player resided in a single group. A linear model was iteratively trained using 9 of the 10 groups, and then its accuracy was evaluated on the held-out group (Figure A1).

The performance of the model was then evaluated by comparing estimated normalized drives per minute to the ground-truth values for all 2013-2017 player-seasons. The mean R^2 value between estimated and ground-truth values
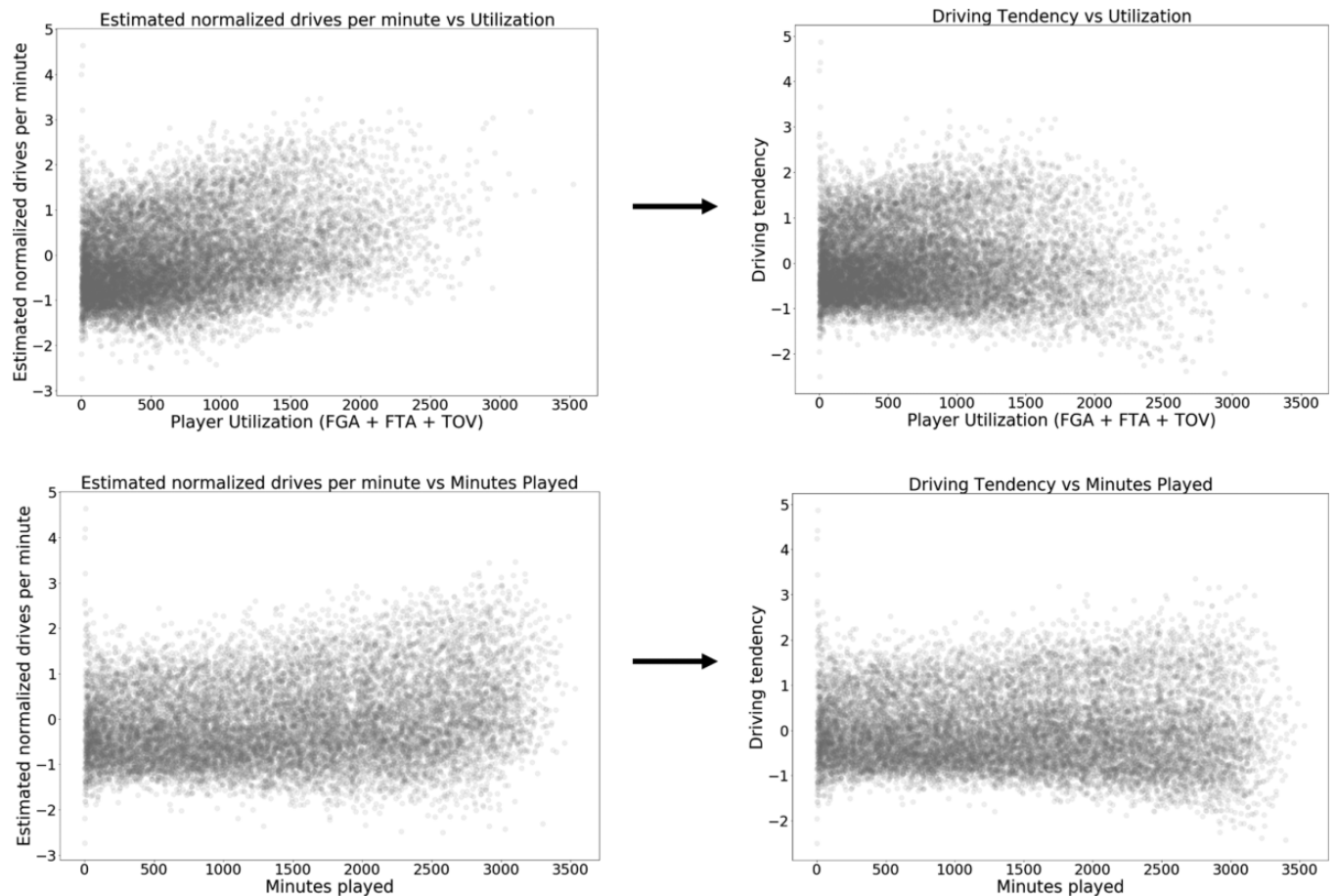
Figure A2. Controlling for utilization and minutes played to calculate driving tendency. After estimating the normalized drives per minute for each player-season, we controlled for minutes played and driving tendency. Each point in each plot is a player-season. The left plots display the relationship between estimated normalized drives per minute before controlling for these variables, and the right plots display the relationship after controlling for these variables. The top plots display the effect of controlling for utilization, and the bottom plots display the effect of controlling for minutes played. FGA, field goal attempt; FTA, free throw attempt; TOV, turnover.

across the 10 models was 0.741 ± 0.040. The mean error across the 10 models was $0.002 \pm .038$, indicating that the model does not contain significant bias. The mean error magnitude across the 10 models was 0.489 ± 0.048. The units for mean error and mean error magnitude were SDs from the mean drives per minute. The mean estimated signal-to-noise ratio for the final model was 3.530 ± 1.070. This strong signal-to-noise ratio allowed us to detect true differences in driving tendencies between player-seasons.

The model was then trained using data from all 2013-2017 player-seasons and applied to all player-seasons between 1980 and 2017 to obtain an estimated normalized drive per minute for all player-seasons.

4. Controlling for minutes played and utilization

Simply being on the court, playing basketball, and having possession of the ball carries some baseline risk of anterior cruciate ligament injury. However, our question was not on whether playing basketball is riskier than sitting on the sidelines. Our focus was on whether driving the ball to the basket is a riskier maneuver than other actions a player might use. During initial experiments, we found that playing more minutes and being given the ball more frequently (ie, higher utilization) were correlated with drives per minute.

To eliminate this potential confounding, we adjusted every player-season's normalized drives per minute metric to control for minutes played and utilization (Figure A2). To control for these variables, we performed linear regression such that the inputs to the model were players' minutes played and utilization and the output was their estimated normalized drives per minute. We then subtracted the estimate of this model from estimated normalized drives per minute. Thus, we define a player-season's "driving tendency" as its estimated normalized drives per minute after subtracting the component of this metric that is linearly associated with minutes played and utilization. This causes driving tendency to no longer be correlated with minutes played or utilization.