

Concussion Incidence and Impact on Player Performance in Major League Baseball Players Before and After a Standardized Concussion Protocol

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Background: Sports-related concussions have garnered significant attention in recent years because of the negative effects they can have on a player's cognitive health and performance. In response to this growing concern, Major League Baseball (MLB) introduced a standardized concussion protocol during the 2011-2012 season.

Purpose/Hypothesis: The purpose of this study was to compare the reported incidence of concussions and the subsequent performance of MLB players before and after the introduction of the standardized concussion protocol. We hypothesized that the introduction of the standardized concussion protocol would not have an impact on player performance postconcussion.

Study Design: Cohort study; Level of evidence, 3.

Methods: Players who suffered a concussion between 2001 and 2018 were identified from the MLB transactions page. Incidence and player performance were compared before and after the introduction of the standardized concussion protocol. Player performance was evaluated using traditional data and sabermetric data, which are advanced statistics used in conjunction with standard statistics to better compare players and teams. Player averages were calculated and compared using paired *t* tests for 30 days before and after concussion, 1 year before and after concussion, and career before and after concussion. Averages were also compared before and after the institution of the standardized concussion protocol using independent-measures *t* tests.

Results: There were a total of 114 players who suffered 142 concussions, with 77% of those occurring after the introduction of the concussion protocol (32 before, 110 after). The average time missed because of concussion significantly decreased from 33.7 days (range, 10-122 days) to 18.9 days (range, 6-111 days) after the concussion protocol ($P = .0005$). There was no difference in player performance (including batting average, on-base percentage, and slugging for batters; earned run average, fielding-independent pitching, and walks plus hits per inning pitched for pitchers) after concussion at any time point (30 days, 1 year, or career) when comparing these statistics before versus after the MLB concussion protocol. However, batter performance was significantly poorer 1 year after concussion and over the remainder of the players' careers ($P < .05$).

Conclusion: The number of reported concussions increased after the introduction of the MLB concussion protocol. However, players spent significantly less time on the disabled list without any adverse effect on player performance. Despite these changes, long-term batting performance was significantly poorer after concussion.

Keywords: traumatic brain injury; head injury; batting; pitching

It has been estimated that 1.6 million to 3.8 million sports-related concussions occur each year in the United States, including those that go unreported.²⁵ The American Medical Society for Sports Medicine has defined concussion as “a traumatically induced transient disturbance of brain function.”²² Concussions often affect one's neurocognitive

abilities, which several studies^{6,16} have shown may remain decreased well after concussion symptoms subside. There has been growing attention to concussions in contact sports such as hockey and football, with various studies seeking to better understand the negative effects of concussions and the protocols made to protect players.^{7,41} When comparing the concussion protocols of the National Football League (NFL), National Hockey League (NHL), Major League Baseball (MLB), and National Basketball Association (NBA), all of the professional leagues require some form

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of baseline neurological testing, whereas only the NBA and NFL mandate preseason concussion education. The MLB is the only organization with a minimum amount of time required on the disabled list (DL) before return to play.¹²

Some of the most prominent neurological tests used for concussion diagnosis are Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) and the Sport Concussion Assessment Tool, version 5 (SCAT5). Players regularly take a battery of tests at the start of the season and are tested again when a concussion is suspected. They are then required to return to baseline performance before returning to play. Studies^{1,31} have shown that while these tests are helpful tools, they may not have high enough sensitivity to protect athletes from the dangerous effects of concussions. In 2010, MLB and the Major League Baseball Players Association (MLBPA) agreed to mandate that all major and minor league teams use the same electronic medical record and leaguewide injury-tracking system. This was meant to allow them to track medical histories of players longitudinally as they moved across major and minor league affiliates and to study the epidemiology of injuries. During the first year of this electronic system, 161 concussions were recorded in the minor league and 29 in the major league, pointing to the need for improved concussion management.¹⁸

MLB responded to this growing concern regarding concussions and the impact on player performance by implementing a standard concussion protocol at the start of the 2011-2012 season.^{21,28,36,39} The protocol requires preseason neurocognitive baseline testing in the form of the SCAT5, use of the SCAT5 as a standardized concussion screening tool during play, the addition of a 7-day DL exclusively for concussed players, neurological evaluation demonstrating a return to baseline before returning to play, and prohibition of same-day return to play. The MLB concussion management protocol also states that concussion diagnosis is made by a certified athletic trainer with the use of SCAT5 and best clinical judgment.²¹ In 2014, MLB also implemented a new protocol (informally called the “Buster Posey Rule”)³⁴ to reduce collisions, and thereby concussion incidence, at home plate. The rule specified that “a runner attempting to score may not deviate from his direct pathway to the plate in order to initiate contact with the catcher” and “unless the catcher is in possession of the ball, the catcher cannot block the pathway of the runner as he is attempting to score.”³⁰

Concussions have been shown to negatively affect NHL players by decreasing career length, reducing post-concussion contract salary, and decreasing performance as measured by scoring.³³ Concussions can have similar debilitating effects on MLB players, and these protocols have been implemented to try to ameliorate such effects.

MLB and team physicians are working on improving player safety and well-being, and as such, the protocols that are in place need to be objectively evaluated so that they can be improved upon. The primary objective of this study was to compare concussion incidence and postconcussion player performance before versus after the introduction of the MLB standardized concussion protocol.

METHODS

Study Design

Data were collected on concussion occurrence among MLB players from 2001 to 2018 during the regular season and postseason. Players who had been placed on the DL with concussions were identified by searching the term “concussion” on the online transactions pages of www.mlb.com and www.baseballprospectus.com.^{2,27} All players who had concussions during the regular season and postseason were included, excluding those who suffered concussions during spring training or while playing in the minor leagues. A comparison was made between players who sustained concussions from 2001 to 2010 with those who did from 2011 to 2018. Mechanism of concussion was also evaluated before and after the introduction of the Buster Posey Rule³⁴ (2014-2015 season).

Characteristics

Player position and number of days missed because of concussion were gathered from www.mlb.com by searching for individual player statistics.²⁷ Players who did not return to play during the season were excluded from the statistical comparison. Age at time of concussion and number of seasons played were gathered from www.baseball-reference.com.³ Season number was calculated by including the current season, meaning that if a player was a rookie playing his first season, the season number was 1. Mechanism of injury was gathered from a variety of media sources.^{4,5,10}

Performance

Standard performance metrics analyzed for batters included batting average (BA), on-base percentage (OBP), slugging percentage (SLG), on-base + slugging percentage (OPS), and on-base + slugging percentage plus (OPS+). Sabermetric data for batters included weighted on-base average (wOBA), weighted runs created plus (wRC+), and wins above replacement (WAR). Standard statistics collected for pitchers

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Ethical approval was not sought for the present study.

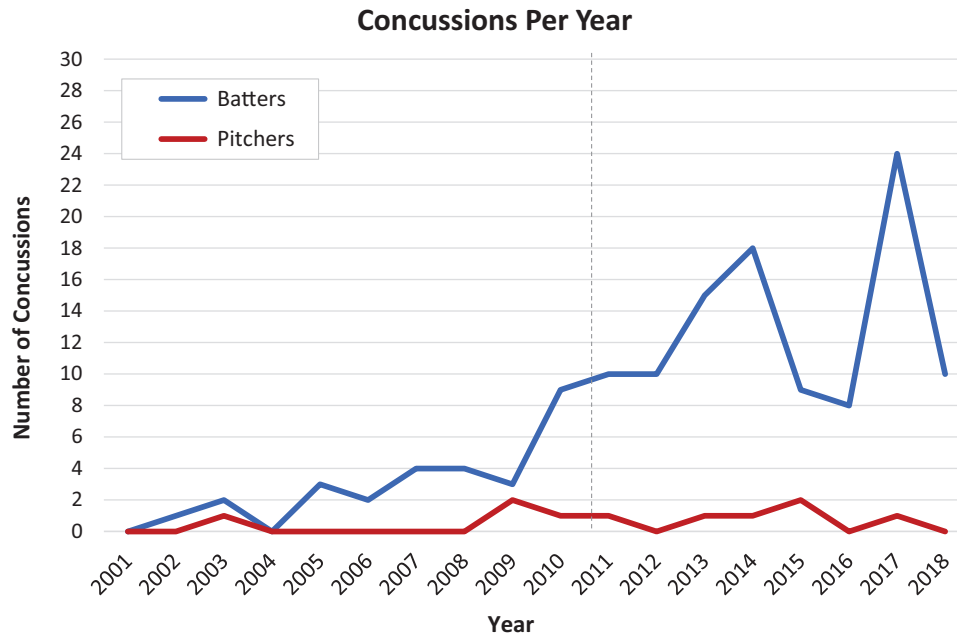


Figure 1. Total number of concussions among batters and pitchers per year from 2001 to 2018. The vertical line at 2011 indicates the implementation of the standardized concussion protocol.

included earned run average (ERA), earned run average plus (ERA+), fielding-independent pitching (FIP), walks plus hits per inning pitched (WHIP), home runs per 9 innings pitched (HR9), walks per 9 innings pitched (BB9), and strikeouts per 9 innings pitched (SO9). Sabermetric data for pitchers included WAR. Appendix Table A1 provides descriptions of these metrics.

Data for 30-day batting and pitching averages were collected from www.mlb.com. Players were included in this part of the analysis if they played consistently for at least 10 calendar days after their concussion.²⁷ Averages from the previous season for BA, OBP, and SLG were used instead of 30-day averages if batters did not play at least 10 calendar days before concussion. The same was done with ERA and WHIP for pitchers. Data comparing 30 days before and after concussion were labeled “30-day interval.”

The BA, OBP, SLG, OPS, and OPS+ were included for batters who played at least 1 year both before and after concussion. Data from the year of the concussion were not included in year averages of either before or after concussion (eg, if a player played from 2003 to 2009 and was injured in 2006, the “before” years included 2003-2005 and the “after” years included 2007-2009, with 2006 excluded) to avoid the confounding factor of performance differences in early- vs late-season concussions. The same was done with ERA, ERA+, FIP, WHIP, HR9, BB9, and SO9 for pitchers. Yearly averages for these were extracted from www.baseball-reference.com.³ Sabermetric data were extracted from www.fangraphs.com.¹⁵ Sabermetric data for batters included wOBA, wRC+, and WAR, and for pitchers it included WAR. Comparisons of 1 year before and after concussion were labeled “1-year window” and included both standard and sabermetric data.

Comparisons of career statistics before and after concussion were labeled “career” and similarly included both standard and sabermetric data. The data then fell under 1 of 3 categories: overall (2001-2018), preprotocol (2001-2010), and postprotocol (2011-2018).

Statistical Analysis

Descriptive statistics were calculated with categorical data reported as frequency with percentages and continuous data as mean \pm SD. Mean comparisons of batting and pitching metrics were made both pre- and postconcussion (30-day, 1 year, and career) as well as before and after the institution of the concussion protocol (ie, 2001-2010 compared with 2011-2018) using paired *t*-tests. $P < .05$ was interpreted as statistically significant. All statistical analyses were performed using SAS 9.4 (SAS Institute Inc).

RESULTS

Incidence and Characteristics

There were 30 players with concussions from 2001 to 2010, 90 from 2011 to 2018, and 114 from 2001 to 2018. Six players sustained concussions during both time periods. There were 32 concussions from 2001 to 2010 (4 pitchers) and 110 concussions from 2011 to 2018 (6 pitchers) (Figure 1). Two players had multiple concussions from 2001 to 2010, whereas 17 players had multiple concussions from 2011 to 2018. The average age at the time of concussion was 29 years from 2001 to 2010 and 28.5 years from 2011 to 2018. The number of seasons played among concussed players was 5.5 from 2001 to 2010 and 6.1 from

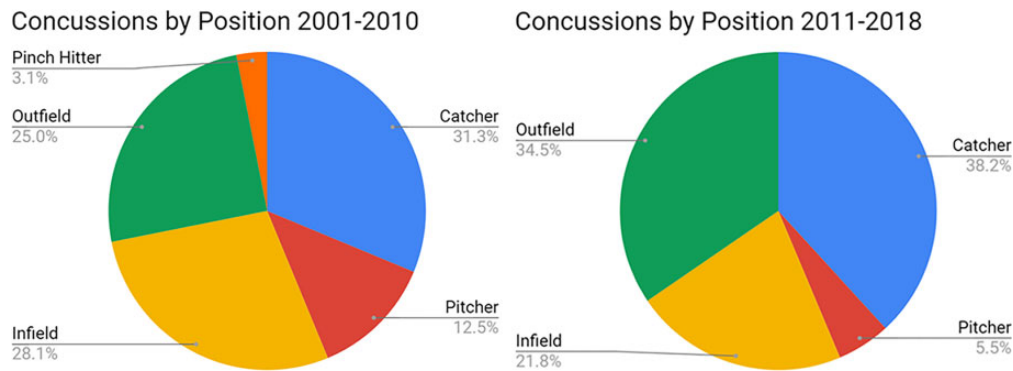


Figure 2. Player position percentages for pre- and poststandardized concussion protocol.

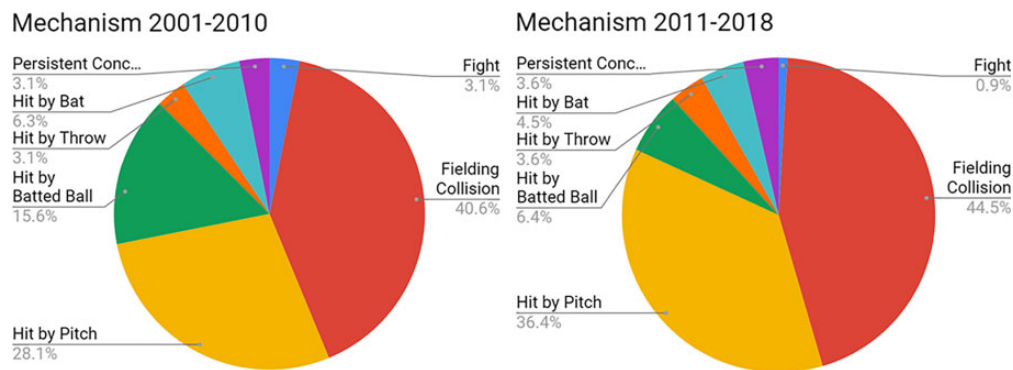


Figure 3. Mechanism of injury percentages for pre- and poststandardized concussion protocol. Conc, concussion.

2011 to 2018. The position with the highest frequency of concussions was catcher, both before (31.3%) and after (38.2%) the introduction of the concussion protocol. However, from 2014 to 2018, outfielders (37.0%) were more commonly concussed than catchers (35.6%) (Figure 2).

Mechanism of Injury

Both before and after the introduction of the standardized concussion protocol, the most common mechanism of injury was fielding collision, which included colliding with other players, hitting the ground, running into walls, and diving. The next most common mechanism of injury was hit by pitch, which included direct pitches and foul tips. Of note, all 10 pitchers who sustained concussions were hit by a batted ball. Additionally, 8 catchers had concussions from home plate collisions from 2007 to 2013, whereas no concussions resulted from home plate collisions from 2014 to 2018. Finally, over the study period, 29 catchers and 13 outfielders sustained concussions, from foul tips and collisions with the outfield wall, respectively (Figure 3).

Injury Time

The average time missed because of concussion significantly decreased from 33.7 days (range, 10-122 days) from

2001 to 2010 to 18.9 days (range, 6-111 days) from 2011 to 2018 ($P = .0005$). Pitchers missed a significantly greater number of days than batters; 72.7 days (compared with 28.1 days) from 2001 to 2010 and 28.8 days (compared with 18.3 days) from 2011 to 2018 ($P = .0005$ for both periods). From 2001 to 2010, 70% (21/30) of the players returned during the same season and continued to play after, 13.3% (4/30) returned the next season, 13.3% (4/30) did not return to play, and 3.3% (1/30) returned the season of the concussion but did not play another season. From 2011 to 2018, 80% (72/90) of the players returned during the same season and continued to play after, 11.1% (10/90) returned the next season, 3.3% (3/90) did not return to play, 4.4% (4/90) returned the season of the concussion but did not play another season, and 1.1% (1/90) returned the season of the concussion but then missed the following 2 seasons.

Performance

30-Day Interval

There were no significant differences in player (either batter or pitcher) performance 30 days before and after concussion when comparing performance metrics before versus after the implementation of the standardized concussion protocol in 2011 (Table 1).

TABLE 1
Batter and Pitcher Performance Metrics Comparing 30 Days Before and After Concussion^a

Statistic	30-Day Interval					
	Overall		2001-2010		2011-2018	
	Before	After	Before	After	Before	After
BA	0.250	0.246	0.241	0.240	0.252	0.247
OBP	0.326	0.318	0.322	0.311	0.327	0.320
SLG	0.401	0.389	0.406	0.379	0.400	0.392
ERA	3.74	4.59	6.27	9.10	2.73	2.79
WHIP	1.35	1.49	1.47	1.85	1.29	1.34

^aAll values are reported as averages. BA, batting average; ERA, earned run average; OBP, on-base percentage; SLG, slugging percentage; WHIP, walks plus hits per inning pitched.

TABLE 2
Batter Standard and Sabermetric Performance Metrics Comparing
Either 1 Year Before and After Concussion or Career Before and After Concussion^a

Statistic	1-Year Window						Career					
	Overall		2001-2010		2011-2018		Overall		2001-2010		2011-2018	
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
BA	0.258 ^b <i>P</i> = .001	0.238 ^b <i>P</i> = .001	0.263	0.243	0.257	0.236	0.254 ^b <i>P</i> < .001	0.238 ^b <i>P</i> < .001	0.256	0.236	0.254	0.240
OBP	0.328 ^b <i>P</i> = .022	0.315 ^b <i>P</i> = .022	0.333	0.316	0.327	0.314	0.325 ^b <i>P</i> = .002	0.310 ^b <i>P</i> = .002	0.327	0.306	0.325	0.312
SLG	0.411 ^b <i>P</i> = .004	0.376 ^b <i>P</i> = .004	0.448	0.374	0.400	0.377	0.404 ^b <i>P</i> = .015	0.382 ^b <i>P</i> = .015	0.420	0.369	0.400	0.389
OPS	—	—	—	—	—	—	0.729 ^b <i>P</i> = .005	0.693 ^b <i>P</i> = .005	0.747	0.674	0.725	0.701
OPS+	—	—	—	—	—	—	96.4 ^b <i>P</i> = .009	87.8 ^b <i>P</i> = .009	93.7	82.0	97.5	90.2
wOBA	0.323 ^b <i>P</i> = .004	0.304 ^b <i>P</i> = .004	0.337	0.304	0.319	0.304	0.314 ^b <i>P</i> = .003	0.295 ^b <i>P</i> = .003	0.322	0.287	0.312	0.299
wRC+	99.8 ^b <i>P</i> = .009	88.7 ^b <i>P</i> = .009	100.7	84.2	99.5	90.1	92.3 ^b <i>P</i> = .022	82.8 ^b <i>P</i> = .022	91.2	75.0	92.7	86.1
WAR	1.66 ^b <i>P</i> = .007	1.13 ^b <i>P</i> = .007	1.60	1.12	1.68	1.14	1.32 ^b <i>P</i> = .005	0.91 ^b <i>P</i> = .005	1.08	0.73	1.37	1.08

^aAll values are reported as averages. BA, batting average; OBP, on-base percentage; OPS, on-base + slugging percentage; OPS+, on-base + slugging percentage plus; SLG, slugging percentage; WAR, wins above replacement; wOBA, weighted on-base average; wRC+, weighted runs created plus. Dashes denote those statistics that were not available for that time interval.

^bDenotes a significant difference (*P* < .05).

1-Year Window

Batters demonstrated a statistically significant postconcussion decline in all standard (BA, OBP, and SLG) and sabermetric (wOBA, wRC+, and WAR) performance measures 1 year after concussion (*P* < .05) (Table 2). However, there were no significant differences in batter performance when comparing preprotocol versus postprotocol data.

Pitchers were found to have significantly more BB9 1 year after concussion (*P* = .024) (Table 3). However, no significant differences in pitcher performance metrics were noted during the 1-year window when comparing the pre- versus postprotocol time periods.

Career

Batters had a statistically significant drop in every traditional (BA, OBP, SLG, OPS, and OPS+) and sabermetric (wOBA, wRC+, and WAR) performance measure over the remainder of their career after concussion (*P* < .05) (Table 2). No differences in batter performance were noted when comparing the pre- versus postprotocol time points.

Pitchers had a statistically significant increase in HR9 during the remainder of their career after concussion (*P* = .023) (Table 3). There were no statistically significant differences in career pitcher performance after concussion when comparing pre- versus postprotocol data.

TABLE 3
Pitcher Standard and Sabermetric Performance Metrics Comparing
Either 1 Year Before and After Concussion or Career Before and After Concussion^a

Statistic	1-Year Window						Career					
	Overall		2001-2010		2011-2018		Overall		2001-2010		2011-2018	
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
ERA	3.82	3.78	4.53	4.56	3.54	3.47	4.07	3.98	4.53	4.54	3.84	3.69
ERA+	—	—	—	—	—	—	103.3	108.7	96.0	95.5	107	115.3
FIP	3.56	3.88	4.36	4.08	3.24	3.08	3.84	4.20	4.36	4.26	3.58	4.57
WHIP	—	—	—	—	—	—	1.33	1.36	1.24	1.43	1.37	1.33
HR9	0.73	0.80	1.05	1.03	0.61	0.70	0.80 ^b	1.08 ^b	1.05	1.15	0.56	1.15
							<i>P</i> = .023	<i>P</i> = .023				
BB9	2.67 ^b	3.55 ^b	2.34	2.91	2.80	3.81	3.12	3.40	2.35	2.80	3.50	3.82
	<i>P</i> = .024	<i>P</i> = .024										
SO9	7.44	7.49	5.12	6.88	8.36	7.74	7.00	7.68	5.12	6.70	7.95	7.31
WAR	1.39	1.70	1.75	2.1	1.24	1.54	1.16	1.26	1.75	1.74	0.71	0.81

^aAll values were reported as averages. BB9, bases on balls (walks) per 9 innings pitched; ERA, earned run average; ERA+, earned run average plus; FIP, fielding-independent pitching; HR9, home runs per 9 innings pitched; SO9, strikeouts per 9 innings pitched; WAR, wins above replacement; WHIP, walks plus hits per inning pitched. Dashes denote those statistics that were not available for that time interval.

^bDenotes a significant difference ($P < .05$).

DISCUSSION

The current study found a significant increase in the reported incidence of concussions after the introduction of the MLB standardized concussion protocol during the 2011-2012 season. In addition, both position players and pitchers missed significantly less time with the introduction of the 7-day DL, and there was no significant difference in player performance between the preprotocol and postprotocol periods. Despite the introduction of the concussion protocol, batters were noted to have declining performance in all traditional and sabermetric measures both 1 year after concussion as well as throughout the remainder of their career. Finally, the study also found that the Buster Posey Rule³⁴ reduced the incidence of concussions due to home plate collisions (Figure 3).

The increase in reported incidence of concussions noted in the current study is similar to the findings of Schwindel et al,³⁹ who demonstrated that concussion incidence was on the rise leading up to the 2011-2012 season during which the standardized concussion protocol was introduced. Analogous to our own findings, they also showed that catchers had the most concussions among position players and that players were sidelined for an average of 32 days post-concussion. The improvement of concussion testing over the years, such as new versions of the SCAT in 2008, 2012, and 2016, can account for some of this increase in incidence.^{8,13,35} The recent rise in societal interest and awareness is likely another factor.³⁷ In addition, Sabesan et al³⁸ hypothesized that the continued rise in incidence after 2011 is related to an increase in reporting by players who desire a short recovery period and are more agreeable to being placed on a 7-day DL than the traditional 15-day DL. In contrast to our study, Sabesan et al reported that after 2011, players missed 31 days postconcussion as

compared with the lower average of 18 days in NHL. The current study demonstrated a decrease from 33 days pre-protocol to 18 days postprotocol, which is more consistent with the time missed by NHL players.^{38,41}

There are various potential explanations for this decrease in missed days after implementation of the protocol. One is that concussions for which players were placed on the 15-day DL were likely more severe. It may be that some players with minor concussions were not placed on the DL because of a lack of specific protocol and a desire for them to play soon. Alternatively, players with minor concussions who were placed on the 15-day DL would have had to sit out for 15 days even if they were ready to return in 7, artificially inflating their time out compared with the 7-day DL. Many concussions do resolve within a shorter time frame, and as such, an increased reported incidence after introduction of a concussion protocol is likely more representative of the spectrum of the injury.

In another study examining the effects of concussion among professional baseball players, Ramkumar et al³⁶ found that batters had a significant decrease in BA and OBP postconcussion, both before and after 2011. These findings are in keeping with the current study, which also demonstrated a significant drop in sabermetric performance measures such as wOBA, wRC+, and WAR. This study, however, demonstrated that the introduction of a standardized concussion protocol did not have a significant impact on improving player performance in the short or long term, as short-term metrics both pre- and postprotocol were unchanged by concussion, while long-term metrics declined. Multiple factors may contribute to the long-term performance decline, including more significant concussion histories, concomitant injuries not related to head trauma, and a gradual performance decline in aging athletes. Player performance may improve through a more individualized

approach to the treatment of concussions, as stressed in the 2019 position statement by the American Medical Society for Sports Medicine on concussion in sport.²² The statement stresses the emerging concept of classifying concussions by symptom types, labeled “clinical profiles,” and applying specific treatments to help resolve the wide array of concussion symptoms.

The finding that pitchers were out significantly longer than position players before they returned to play may be related to the fact that pitchers do not wear helmets despite the average line-drive hit traveling at 83 miles per hour (MPH) by the time it reaches them on the mound. Meanwhile, batters, who routinely face a fastball traveling 91 to 93 MPH, have been required to wear helmets since 1971.^{11,24} With such comparable speeds, pitchers are certainly in danger when the ball is hit directly at them. While there are no mandatory requirements for pitcher head protection, the MLB has approved a padded cap that is rated to protect the pitcher’s head from a ball traveling up to 90 MPH in the front and 85 MPH on the sides.²⁹ However, its routine use among pitchers in the major leagues is quite poor because of its awkward fit and appearance.²⁹ The use of formal helmets among pitchers may not be a feasible option either, as it has been suggested that they may interfere with a pitcher’s biomechanics, potentially resulting in a greater risk of injury.²⁰

Green et al¹⁷ compared the number of concussions at home plate from 2011-2013 to 2014-2015 to evaluate the impact of the 2014 Buster Posey Rule.³⁴ They reported an average of 13 home plate concussions per year in both Minor League Baseball and MLB from 2011 to 2013, compared with none during the 2014-2015 season. Our study demonstrates that there was a continued lack of concussions from home plate collisions between 2014 and 2018.

With 29 concussions in catchers caused by foul balls, face masks are an important safety issue. The discussion on face masks includes factors of safety, comfort, and convenience. Green et al¹⁹ demonstrated that while 71% of catchers wear conventional-style masks and 30% wear hockey-style masks, wearers of both styles selected hockey-style masks as safer and more protective. Conventional mask wearers reported that their mask style was easier to remove, but wearers of both styles stated that their chosen style gave them better visibility and more comfort. Another study tested both traditional and hockey-style masks and found through linear accelerations and angular rates that the hockey style had superior safety performance.¹⁴ There are also designs such as the Force3 Defender mask, with built-in springs to absorb some of the impact from a foul ball.²⁶ Similarly, Janda²³ advocated for improving outfielder safety through the use of padded outfield walls. Mandating such padding across MLB stadiums would lessen the chance of concussion during an outfield collision.³² Further research on pitcher and catcher head protection as well as outfield wall padding efficacy is needed to assist the MLB in decreasing concussion incidence and increasing player safety.

This study is not without its limitations. First, data were obtained from published online records and media sources, and access to medical charts was not possible to confirm the

diagnosis of a concussion.^{2,27} Second, as it is not mandatory for players with concussions to be placed on the DL, there may be some who sustained concussions that are not reported, thereby leading to an underestimation of the true incidence of concussion among MLB players.⁴⁰ Third, players may have had a concussion during spring training and the off-season that was not captured in the current study, and these concussions may have affected their neurocognitive abilities. Finally, although there was no control group of players with alternate injuries or returning from nonmedical leave to compare performance measures, the current study used each player’s preconcussion performance as an internal control to evaluate the impact of concussion.^{9,36} Future research needs to be done with access to medical charts to identify players with concussions and specify mechanism of injury. Comparisons should be made with a control group of players with alternate injuries or returning from nonmedical leave to better determine the effects of concussion on performance both in the short and long term.

CONCLUSION

The reported incidence of concussions among MLB players increased significantly after the introduction of a standardized concussion protocol. However, players spent significantly less time on the DL, without any adverse effect on traditional and sabermetric player performance measures. Despite these changes, long-term (1 year and career) batting performance was significantly poorer after concussion. Further measures aimed at concussion prevention, such as the 2014 Buster Posey Rule, are required to counteract this growing issue within professional baseball.

REFERENCES

1. Alsalaheen B, Stockdale K, Pechumer D, Broglio SP. Validity of the Immediate Post Concussion Assessment and Cognitive Testing (ImPACT). *Sports Med*. 2016;46(10):1487-1501.
2. Baseball Prospectus. Baseball prospectus. *Baseball Prospectus, LLC*. <https://legacy.baseballprospectus.com/sortable/>. Accessed March 30, 2019.
3. Baseball Reference. Baseball reference. *Sports Reference LLC*. <https://www.baseball-reference.com/>. Accessed November 1, 2018.
4. Bell M. Cervelli placed on 7-day concussion DL. *Major League Baseball*. <https://www.mlb.com/news/francisco-cervelli-placed-on-concussion-dl-c234989730>. Accessed December 1, 2018.
5. Berry A. Cobb hit in head by liner, has mild concussion. *Major League Baseball*. <https://www.mlb.com/news/alex-cobb-hit-in-head-by-liner-has-mild-concussion/c-50727980>. Accessed November 15, 2018.
6. Broglio SP, Macciocchi SN, Ferrara MS. Neurocognitive performance of concussed athletes when symptom free. *J Athl Train*. 2007;42(4):504-508.
7. Casson IR, Viano DC, Powell JW, Pellman EJ. Twelve years of National Football League concussion data. *Sports Health*. 2010;2(6):471-483.
8. Chin EY, Nelson LD, Barr WB, McCrory P, McCrea MA. Reliability and validity of the Sport Concussion Assessment Tool-3 (SCAT3) in high school and collegiate athletes. *Am J Sports Med*. 2016;44(9):2276-2285.

9. Chow BH, Stevenson AM, Burke JF, Adelman EE. The effect of concussion on batting performance of major league baseball players. *Open Access J Sports Med.* 2019;10:41-48.
10. Christensen J. Morneau has mild concussion symptoms. *StarTribune.* <http://www.startribune.com/morneau-has-concussion-symptoms/128695123/>. Accessed December 15, 2018.
11. Clair M. Are pitchers really throwing harder than ever? *CUT4 by mlb.com.* <https://www.mlb.com/cut4/are-pitchers-really-throwing-harder-than-ever/c-292153594>. Accessed May 29, 2019.
12. Cochrane GD, Owen M, Ackerson JD, Hale MH, Gould S. Exploration of US men's professional sport organization concussion policies. *Phys Sportsmed.* 2017;45(2):178-183.
13. Echemendia RJ, Meeuwisse W, McCrory P, et al. The Sport Concussion Assessment Tool 5th Edition (SCAT5): Background and rationale. *Br J Sports Med.* 2017;51(11):848-850.
14. Eckersley CP, White TR, Cutcliffe HC, Shridharani JK, Wood GW, Bass CR. Foul tip impact attenuation of baseball catcher masks using head impact metrics. *PLoS One.* 2018;13(6):e0198316.
15. Fangraphs. Fangraphs. <https://www.fangraphs.com/>. Accessed December 15, 2018.
16. Fazio VC, Lovell MR, Pardini JE, Collins MW. The relation between post concussion symptoms and neurocognitive performance in concussed athletes. *NeuroRehabilitation.* 2007;22(3):207-216.
17. Green G, D'Angelo J, Coyles J, Valadka A. Effect of a rule change on concussions and other injuries in professional baseball [abstract]. *Br J Sports Med.* 2017;51(11):A64-A65.
18. Green GA, Pollack KM, D'Angelo J, et al. Mild traumatic brain injury in major and Minor League Baseball players. *Am J Sports Med.* 2015;43(5):1118-1126.
19. Green GA, Porter KP, Conte S, Valadka AB, Soloff L, Curriero FC. Preventing concussions from foul tips and backswings in professional baseball: catchers' perceptions of and experiences with conventional and hockey-style masks [published online October 23, 2018]. *Clin J Sport Med.* doi: 10.1097/JSM.0000000000000679.
20. Gregory S. Why pitchers won't be wearing helmets, even after latest scare. *TIME.* <http://keepingscore.blogs.time.com/2013/05/09/why-pitchers-wont-be-wearing-helmets-even-after-latest-scare/>. Accessed May 21, 2019.
21. Halem DR. 2017-2021 Basic agreement. <https://www.fdtmedia.com/wp-content/uploads/2018/10/Basic-Agreement-ENG.pdf>. Accessed May 28, 2019.
22. Harmon KG, Clugston JR, Dec K, et al. American Medical Society for Sports Medicine position statement on concussion in sport. *Clin J Sport Med.* 2019;29(2):87-100.
23. Janda DH. The prevention of baseball and softball injuries. *Clin Orthop Relat Res.* 2003;409:20-28.
24. Jiang JJ, Leland JM. Analysis of pitching velocity in major league baseball players before and after ulnar collateral ligament reconstruction. *Am J Sports Med.* 2014;42(4):880-885.
25. Langlois JA, Rutland-Brown W, Wald MM. The epidemiology and impact of traumatic brain injury: a brief overview. *J Head Trauma Rehabil.* 2006;21(5):375-378.
26. Lucas P. Catchers spring into action with new mask. *ESPN.com.* 04/19/2018. http://www.espn.com/mlb/story/_/id/23257777/catchers-latest-benefit-new-era-protection-force3-defender-mask. Accessed March 30, 2019.
27. Major League Baseball. MLB.com. <https://www.mlb.com/>. Accessed November 1, 2018.
28. Major League Baseball. Major League Baseball and Major League Baseball Players Association announce new protocols on concussions. http://mlb.mlb.com/content/primer_friendly/mlb/y2011/m03/d29/c17181944.jsp. Accessed February 9, 2019.
29. Major League Baseball. MLB approves padded cap for pitchers. <https://www.mlb.com/news/major-league-baseball-approves-padded-cap-for-pitchers/c-67202016>. Accessed May 21, 2019.
30. Major League Baseball. MLB, MLBPA adopt Experimental Rule 7.13 on home plate collisions. <https://www.mlb.com/news/mlb-mlbpa-adopt-experimental-rule-713-on-home-plate-collisions/c-68268622>. Accessed February 9, 2019.
31. Manderino LM, Gunstad J. Performance of the immediate post-concussion assessment and cognitive testing protocol validity indices. *Arch Clin Neuropsychol.* 2018;33(5):596-605.
32. Moss A. No excuse for MLB not to mandate outfield wall padding. *Locked On Yankees.* <https://www.lockedonyankees.com/yankees/no-excuse-for-mlb-not-to-mandate-outfield-wall-padding/>. Accessed March 30, 2019.
33. Navarro SM, Pettit RW, Haeberle HS, et al. Short-term impact of concussion in the NHL: an analysis of player longevity, performance, and financial loss. *J Neurotrauma.* 2018;35(20):2391-2399.
34. Perry D. Controversial home plate blocking rule comes into play in Cubs-Dodgers NLCS Game 1. *CBS SPORTS DIGITAL.* <https://www.cbssports.com/mlb/news/controversial-home-plate-blocking-rule-comes-into-play-in-cubs-dodgers-nlcs-game-1/>. Accessed November 6, 2019.
35. Putukian M, Echemendia R, Dettwiler-Danspeckgruber A, et al. Prospective clinical assessment using Sideline Concussion Assessment Tool-2 testing in the evaluation of sport-related concussion in college athletes. *Clin J Sport Med.* 2015;25(1):36-42.
36. Ramkumar PN, Navarro SM, Haeberle HS, et al. Short-term outcomes of concussions in Major League Baseball: a historical cohort study of return to play, performance, longevity, and financial impact. *Orthop J Sports Med.* 2018;6(12):2325967118814238.
37. Register-Mihalik JK, Kay MC. The current state of sports concussion. *Neurol Clin.* 2017;35(3):387-402.
38. Sabesan VJ, Prey B, Smith R, Lombardo DJ, Borroto WJ, Whaley JD. Concussion rates and effects on player performance in Major League Baseball players. *Open Access J Sports Med.* 2018;9:253-260.
39. Schwindel LE, Moretti VM, Watson JN, Hutchinson MR. Epidemiology and outcomes of concussions in Major League Baseball. *Ann Orthop Rheumatol.* 2014;2(3):1022.
40. Wasserman EB, Abar B, Shah MN, Wasserman D, Bazarian JJ. Concussions are associated with decreased batting performance among Major League Baseball players. *Am J Sports Med.* 2015;43(5):1127-1133.
41. Wennberg RA, Tator CH. Concussion incidence and time lost from play in the NHL during the past ten years. *Can J Neurol Sci.* 2008;35(5):647-651.

APPENDIX

TABLE A1
 Explanations of Batter and Pitcher Statistics

Statistic	Definition	Explanation
For batters		
BA	Batting average	Number of hits divided by at bats. The oldest and most traditional batting metric.
OBP	On-base percentage	Measure of how often a batter reaches base.
SLG	Slugging percentage	Total number of bases divided by number of at bats.
OPS	On-base + slugging percentage	Combines OBP and SLG and represents how well a hitter can reach base and how well he can hit for average and for power.
OPS+	On-base + slugging percentage plus	Normalizes OPS across the entire league, accounting for external factors such as ballparks.
wOBA	Weighted on-base average	Version of OBP that accounts for how a player reached base, with greater value for more bases in a hit.
wRC+	Weighted runs created plus	Quantifies runs that a batter has created and normalizes it, taking into account different ballparks and eras.
WAR	Wins above replacement	Measures a player's overall value, determining how many more wins he is worth than a replacement player at his same position.
For pitchers		
ERA	Earned run average	Average number of earned runs a pitcher allows per 9 innings pitched.
ERA+	Earned run average plus	Normalizes ERA across the entire league, accounting for factors such as ballparks and opponents.
FIP	Fielding-independent pitching	Statistic that estimates a pitcher's run prevention independent of the performance of their defense.
WHIP	Walks plus hits per inning pitched	Sum of a pitcher's walks and hits divided by total innings pitched to evaluate how well a pitcher keeps runners off the basepaths.
HR9	Home runs per 9 innings pitched	Average number of home runs a pitcher allows per 9 innings pitched.
BB9	Bases on balls (walks) per 9 innings pitched	Average number of walks a pitcher allows per 9 innings pitched.
SO9	Strikeouts per 9 innings pitched	Average number of strikeouts by a pitcher per 9 innings pitched.
WAR	Wins above replacement	Measures a player's overall value, determining how many more wins he is worth than a replacement player at his same position.