Concussion and National Hockey League Player Performance: An Advanced Hockey Metrics Analysis

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Context: Postconcussion deficits in neurocognitive performance and postural control may persist at the time of return to sport participation. How these deficits, if present, affect athletic performance is largely unknown, with prior studies showing mixed results.

Objective: To evaluate postconcussion National Hockey League player performance using advanced hockey metrics over short- (5 games), medium- (10 games), and long-term (remainder of the season) seasonal performance.

Design: Retrospective cohort study.

Patients or Other Participants: National Hockey League players who sustained a sport-related concussion (SRC; n = 93) and returned during the same season and players (n = 51) who missed time for non–injury-related reasons.

Main Outcome Measure(s): Six performance metrics were used: (1) points per 60 minutes, (2) Corsi percentage, (3) personal Fenwick shooting percentage, (4) scoring chances per 60 minutes, (5) penalty difference, and (6) PDO (not an acronym but sometimes referred to as SVSP% [save percentage shooting percentage]). Performance was compared using 2 (group) \times 2 (time) repeated-measures analyses of variance for 3

time windows: (1) ± 5 games, (2) ± 10 games, and (3) the remainder of the season postconcussion. Alpha values were set at a conservative .01 to account for the lack of independence among dependent variables.

Concussion

Results: No significant interactions were present for any of the 6 dependent variables at any of the 3 time windows. Overall, none of the secondary variables differed.

Conclusions: Using advanced, sport-specific metrics, we found that National Hockey League players did not display worse seasonal performance during 3 postinjury time frames after they sustained an SRC. Whereas laboratory studies have identified lingering neurologic deficits after concussion, our results suggest that these deficits, if present, either do not translate to worse athletic performance or were not captured by these 44 metrics. Further, prospective efforts are needed to accurately quantify performance after SRC among professional hockey players.

Key Words: mild traumatic brain injuries, sports performance, ice hockey

Key Points

- After concussion, National Hockey League (NHL) players' performance was similar to their preconcussion performance across a diverse array of advanced metrics.
- The postconcussion performance of NHL players was similar to that of players with nonconcussion-related time loss.
 If persistent postconcussion deficits existed in NHL players, the current metrics used were unable to identify them,
- suggesting that either no deficits persisted or different metrics are required to identify the deficits.

Lecehockey is a fast-paced, high-risk collision sport played on an enclosed hard surface with skating speeds exceeding 30 miles per hour (48 km/h) and shot speeds over 100 miles per hour (161 km/h).¹ Thus, the high rate of injuries is not surprising, with more than half of all National Hockey League (NHL) players missing at least 1 game per season because of injury.² National Hockey League concussion rates are 5.8 to 6.1 per 100 games, with forwards experiencing disproportionally more concussions (65%) than defensemen (32%) or goalies (3%), with a median time loss of 6 days.^{3,4} Furthermore, concussions most frequently occur during the first period (47%), in the defensive zone (45%), and along the perimeter (53%) after player-to-player contact (85%) involving the shoulder (42%) and impacts to the lateral side of the head (74%).^{3,5} Although rule changes (ie, 2010 implementation of Rule 48, assessing a major penalty for an illegal check to the head; http://www.hockeycentral.co.uk/nhlrules/Rules-48.php) have been implemented, NHL concussion rates have continued to rise, with a 10-fold increase from 1986–1987 through 2011–2012. However, heightened awareness and more conservative concussion-management strategies may partly explain the elevated rates.^{2,6,7}

Most concussed athletes return to premorbid levels of functioning on common clinical examinations within 7 to 10 days⁸; yet these assessments have numerous limitations,

including suboptimal test-retest reliability and an inability to identify subtle neurologic deficits, suggesting that athletes may be returning to participation before complete neurologic recovery.^{9,10} Indeed, deficits persisting beyond clinical recovery have been identified using a variety of laboratory, neuroimaging, electrophysiological, and biomarker protocols, but the clinical meaningfulness of these deficits remains unresolved.⁹ The clinical translation of these studies is unclear, though persistent neurologic deficits are the speculated mechanism underlying the recently identified elevated subsequent musculoskeletal injury rates postconcussion.^{11–17} Thus, continued investigation of the clinical, or real-world, implications is needed to fully elucidate the meaningfulness of these laboratory deficits.

Subtle, yet ongoing, neurologic deficits may also adversely affect player performance. Indeed, the evaluation of player performance in professional sports postconcussion is an emerging research area.^{18–22} After concussion, reduced performance has been noted in both football and baseball players.^{18–22} Player performance postconcussion in the NHL has received limited attention, but Kuhn et al¹⁸ identified no changes in either performance or style of play when assessing hockey performance metrics (eg, goals, points, penalty minutes) over 5 games after players returned from a concussion. More recently, using similar metrics to compare performance in subsequent seasons, Navarro et al²⁰ noted reductions in total points for players who sustained concussions.

The move to advanced metrics beyond simple goals and assists is largely credited as having originated with baseball statistician Bill James and has been adopted by the NHL and other sports.^{23,24} These advanced metrics are believed to provide a more thorough analysis of player performance and may identify more subtle changes not evident in broader measures (eg, goals) that may rely on factors outside the player's control. Subtle but persistent deficits have been noted for several months postconcussion^{11–14}; however, the effect on elite-level athletic performance has received limited attention. Therefore, the purpose of our study was to evaluate NHL player performance using advanced hockey metrics over short- (5 games), medium-(10 games), and long-term (remainder of the season) seasonal performance. Though earlier researchers showed minimal differences in NHL players postconcussion, we hypothesized that advanced performance metrics would demonstrate worse performance among concussed NHL players versus players with non-injury-related time loss.

METHODS

Participants

The participants were NHL players who experienced a publicly documented concussion during the 2008–2009 through the 2014–2015 seasons (7 seasons) previously identified by Kuhn et al.¹⁸ From this list, only the data from players who participated in at least 5 consecutive regular season games, both before and after the concussion but not including the game in which the concussion occurred, were analyzed. Only the first concussion that occurred in the season was assessed, but players who received concussions in multiple seasons (n = 7) were included as separate

events. Goalies were excluded from the study, as the metrics used in this study do not apply to them.

Control players were NHL players who missed game(s) because of non-injury- and non-suspension-related reasons (most commonly classified as personal reasons and often reflecting family-related events such as birth of a child or death of a family member) during the same 7 seasons, who had also been previously identified by Kuhn et al.¹⁸ Similar to the concussion group, all control players had to have been active in at least 5 consecutive regular season games before and after the game(s) missed. If a player had missed a game because of both a concussion and a non-injuryrelated reason, that player was excluded from the study. Finally, players in both groups were excluded if they had sustained a time-loss orthopaedic injury during the 10 games before their concussion and missed game(s) or during the 5 games thereafter, to ensure a "clean" sample and limit other confounding injuries that may have affected performance.¹⁸ This study was deemed exempt by the host institutional review board and thus informed consent from participants was not required.

Performance

We identified performance metrics from the previously publicly available WAR-on-Ice²⁵ Web site, which calculated multiple metrics per player on a game-by-game basis, an approach used by numerous authors.^{18,20,26} Two levels of performance metrics were used. In the primary analysis, 6 commonly used advanced metrics encompassing a broad performance spectrum were identified: (1) points per 60 minutes (Points60), (2) Corsi percentage (Corsi%), (3) personal Fenwick shooting percentage (pFen%), (4) scoring chances per 60 minutes, (5) penalty difference, and (6) PDO (not an acronym but sometimes referred to as SVSP% [save percentage shooting percentage]). These 6 advanced metrics were selected a priori to identify diverse aspects of professional hockey and are continuous variables. Points per 60 minutes is the number of points (goals + assists) scored per 60 minutes of playing time for the individual player. For example, if a player recorded 1 point in 20 minutes of playing time, the player's outcome measure for Points60 would be 3.0. Corsi for (CF) refers to all shots attempted, including shots that are blocked, miss the net, are saved, or are goals when the player is on the ice, and Corsi against (CA) refers to the same for the opposing team. Herein, we used Corsi%, which is calculated as Corsi% = CF/(CF + CA)²⁵ Personal Fenwick shooting percentage is the player's goals scored divided by the number of unblocked shots taken.²⁵ Scoring chances per 60 minutes (SCP60) is the number of scoring chances produced by the player or teammates when the focal player is on the ice.²⁵ Penalty difference is the difference between the penalties taken and drawn by a player, such that a negative number reflects more penalties taken than drawn (ie, a positive number is better).²⁵ The *PDO* is the sum of the on-ice save and shooting percentages, with the league average being 100, and is viewed as "luck"; values higher than 100 are considered lucky and values below 100 are deemed unlucky.25

To more thoroughly address the question of postconcussion performance, we assessed an additional 38 metrics (see Supplemental Table 1, available online at http://dx.doi.org/

Table 1.	Player	Demographics ^a
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Group	Height, cm	Weight, kg	Age, y	Games Missed	Position
		Mea	$n \pm SD$		
Concussion (n = 93)	185.5 ± 5.3	92.5 ± 6.9	27.5 ± 5.0	9.1 ± 8.6	Center: 16 Wing: 36
Control (n = 51)	186.0 ± 6.1	93.2 ± 7.4	27.5 ± 3.8	2.3 ± 3.3	Center: 13 Wing: 25 Defense: 13

^a The groups did not differ in height (P=.661), weight (P=.586), or age (0.923). The concussion group missed a greater number of games (P < .001).

10.4085/1062-6050-200-18.S1). These operational definitions and results from the analyses are provided in Supplemental Table 2.

Data Analysis

Three time periods relative to injury were evaluated: (1) ± 5 games preconcussion and postconcussion, (2) ± 10 games preconcussion and postconcussion, and (3) the entire preconcussion and postconcussion season. This approach includes the 5 or 10 games before the concussion and the 5 or 10 games after return from the concussion but not the game in which the concussion occurred. The third postinjury interval includes all games in that season before and after the concussion but not the game in which the concussion occurred. All players had at least 5 games of data available both before and after the concussion, but 7 players with concussions and 4 control players did not have 10 consecutive games and thus were not included in the 10game or season analysis. We selected these intervals to match the 5-game interval implemented by Kuhn et al¹⁸ to approximate 1 month (ie, 10 games) of postinjury performance, and the entire season was chosen to reflect the longer-term persistent deficits on return from concussion.

Statistical Analysis

Means and standard deviations were calculated for each dependent variable for each of the 3 time periods. A series of 2 (group) \times 2 (time: preconcussion, postconcussion) repeated-measures analyses of variance were computed for each dependent variable and for each of the 3 (5-game, 10-game, season) time periods, and effect sizes were calculated (*small* = 0.02, *medium* = 0.13, *large* = 0.26). Because the variables were not independent, a more conservative analysis α value (.01) was used.

RESULTS

A total of 93 players with concussions (86 individuals; 7 had multiple concussions but in separate seasons) and 51 control players met the inclusion and exclusion criteria. No anthropometric differences were present between groups. However, the concussion group missed more games than the control group (Table 1).

We observed no significant interactions for Points60, Corsi%, pFEn%, SCP60, PenD, or PDO for any of the 3 time windows (Tables 2 through 7, Figure). Furthermore, all interaction effect sizes were below 0.05. Among the secondary variables, only 3 reached statistical significance (P < .01); all had small effect sizes (time on ice, 10 games: P = .010, $\eta = 0.046$; time on ice percentage, 10 games: P = .001, $\eta = 0.077$; time on ice percentage, season: P = .004, $\eta = 0.055$), and in all 3 instances, the concussion participants had decreased absolute or relative playing time (Supplemental Table 2, sections 37 and 38).

DISCUSSION

Persistent postconcussion deficits have been identified using diverse laboratory-based approaches,⁹ yet the clinical significance of these deficits has not been fully elucidated. If neurologic recovery is incomplete at the time of return to play, then poorer athletic performance, particularly at elite levels, would be expected. Indeed, neurologic deficits during a relatively simple task, such as level overground dual-task gait, would likely be exacerbated during elite athletic competition and be identified as performance deficits. However, we failed to identify any performance decrements in 5-game, 10-game, or season-long comparisons between NHL players with reported concussions and those with non-injury-related time loss. Failure to identify postconcussion performance deficits after return to participation by NHL players suggests any of the following: (1) ongoing neurologic deficits at any level were not present

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Table 2.	Points	per 60	Minutes ^a

	Concussion		Control			
Time Frame	Pre	Post	Pre	Post	Interaction P Value	Partial
		Mean	\pm SD			
5 games	1.20 ± 1.19	1.49 ± 1.50	1.57 ± 1.28	1.44 ± 1.59	.185	0.012
10 games	1.26 ± 0.90	1.33 ± 1.08	1.47 ± 1.08	1.44 ± 1.17	.637	0.002
Season	1.23 ± 0.72	1.30 ± 0.84	1.40 ± 0.75	1.43 ± 0.92	.785	0.001

^a No significant group × time interactions occurred for 5 games, 10 games, or the season. *Points per 60 minutes* is the number of points (goals + assists) scored per 60 min of playing time for the individual player.

Table 3. Corsi Percentage^a

	Concussion		Control			
Time Frame	Pre	Post	Pre	Post	Interaction P Value	Partial
		Mean	\pm SD			
5 games	50.1 ± 6.7	51.0 ± 7.4	49.8 ± 8.6	49.0 ± 7.1	.233	0.010
10 games	$50.7~\pm~5.7$	49.9 ± 5.9	$50.1~\pm~6.1$	49.2 ± 5.9	.135	0.016
Season	50.1 ± 5.2	49.7 ± 4.9	50.1 ± 4.9	49.3 ± 5.0	.591	0.002

^a No group × time interactions occurred for 5 games, 10 games, or the season. *Corsi percentage* is calculated as Corsi for/(Corsi for + Corsi against).

Table 4. Personal Fenwick Shooting Percentage^a

	Concussion		Control			
Time Frame	Pre	Post	Pre	Post	Interaction P Value	Partial
		Mea	$n\pmSD$			
5 games	4.4 ± 9.7	4.4 ± 9.8	9.2 ± 20.2	7.4 ± 15.6	.527	0.004
10 games	4.7 ± 7.1	3.9 ± 5.5	7.8 ± 15.0	5.5 ± 6.4	.483	0.003
Season	4.8 ± 4.6	4.3 ± 4.4	6.3 ± 4.9	5.3 ± 4.5	.705	0.001

^a No significant group × time interactions occurred for 5 games, 10 games, or the season. *Personal Fenwick shooting percentage* is the player's goals scored divided by number of unblocked shots taken.

Table 5. Scoring Chances per 60 Minutes^a

	Concussion		Control			
Time Frame	Pre	Post	Pre	Post	Interaction P Value	Partial
		Mean				
5 games	27.5 ± 6.6	26.8 ± 6.8	27.0 ± 7.1	26.1 ± 8.0	.902	0.000
10 games	26.8 ± 5.2	26.6 ± 5.7	26.2 ± 6.2	25.9 ± 6.0	.953	0.000
Season	27.0 ± 4.4	26.6 ± 4.7	26.7 ± 5.0	26.4 ± 5.5	.977	0.000

^a No significant group × time interactions occurred for 5 games, 10 games, or the season. *Scoring chances per 60 minutes* is the number of scoring chances produced by the player or teammate when the focal player is on the ice.

Table 6. Penalty Difference^a

	Concussion		Co	Introl		
Time Frame	Pre	Post	Pre	Post	Interaction P Value	Partial
		Mean	\pm SD			
5 games	0.17 ± 1.21	-0.10 ± 1.54	0.24 ± 2.19	-0.10 ± 1.55	.844	0.000
10 games	0.08 ± 1.06	0.02 ± 0.97	0.19 ± 1.51	0.11 ± 1.10	.904	0.000
Season	0.09 ± 0.92	-0.03 ± 0.68	0.04 ± 0.79	0.04 ± 0.70	.470	0.004

^a No significant group \times time interactions occurred for 5 games, 10 games, or the season.

Table 7. PDO^a

	Concussion		Control			
Time Frame	Pre	Post	Pre	Post	Interaction P Value	Partial
		Mean	\pm SD			
5 games	99.2 ± 7.8	101.5 ± 7.3	101.1 ± 9.5	98.3 ± 8.5	.019	0.047
10 games	$99.4~\pm~5.1$	100.9 ± 6.1	$100.6~\pm~7.2$	$99.0~\pm~5.2$.031	0.032
Season	$99.4~\pm~3.8$	100.0 ± 4.4	99.9 ± 4.1	99.8 ± 4.1	.531	0.003

^a Sometimes referred to as SVSP% (save percentage shooting percentage). No significant group × time interactions occurred for 5 games, 10 games, or the season.



Figure. Individual player performance for points per 60 minutes (Points60) across time points and groups.

after return to play, (2) subtle deficits were present but not at a level that affected performance, (3) deficits were present but the athletes' neurologic compensatory strategies were sufficient to mitigate them, or (4) the diverse advanced performance metrics used were not sensitive to any decrement.

Athletic performance after sport-related injury, including both concussion and musculoskeletal injury, is an area of growing interest.^{18–21,26–30} Among professional ice hockey players, Kuhn et al¹⁸ found no differences within the same season, whereas Navarro et al²⁰ noted fewer points scored in the season postconcussion. Nevertheless, Navarro et al²⁰ compared players with concussions across a longer time period (specifically the season before to the season after the concussion), and the control group consisted of NHL players (n = 937), regardless of other injuries or time loss. Thus, these results could have been influenced by a variety of non-concussion-related considerations. Our results agree with those of Kuhn et al,¹⁸ as no meaningful differences were identified across multiple time windows in the same season using a wide range of diverse advanced metrics. Although we studied mostly the same players as Kuhn et al,¹⁸ this alone does not account for the result given the substantially different time windows and test metrics.

Similarly, in professional football, advanced metrics failed to identify any differences in player performance after concussion, although Kumar et al21 primarily investigated players with concussions who did or did not miss a game. Conversely, Major League Soccer players displayed decreased performance in the years postconcussion, but within-season metrics were not assessed.³¹ Major League Baseball hitters demonstrated reduced hitting performance (batting average, on-base percentage, slugging percentage, and on-base plus slugging) in the first 2 weeks postconcussion, a similar time frame to our 5-game analysis, which failed to identify any differences.¹⁹ As hitting performance is largely driven by neurocognitive functioning (eg. reaction time, attentional focus, visual acuity) and lingering deficits persisting beyond the return-to-play point have frequently been noted, it is not surprising to observe decreased batting performance.^{9,32} However, batting is a highly individualized task, involving precise interaction between the pitcher and batter, whereas football, hockey, and basketball outcomes typically involve the interaction of 12 to 22 players at a time, allowing for a larger margin of error that may mask subpar performance, even when advanced statistical metrics are used. Herein, personal Fenwick shooting percentage was the most individualized

metric, yet it relies on the interactions of numerous additional players. Moving forward, most individualized specific scenarios in hockey (eg, face-offs, shoot-out performance) and football (wide receiver/defensive passing scenario performance) could be assessed to overcome these methodologic limitations.

No single set of advanced metrics has been determined to be the best, but we selected our primary dependent variables to represent diverse aspects of professional hockey. The Corsi and Fenwick values are 2 of the most commonly used hockey metrics and both represent shooting-related aspects of the game. Points per 60 minutes and SCP60 were selected as outcomes that measure "success" normalized to participation time, whereas PenD potentially represents aggressiveness. Still, many of the commonly used metrics, such as goals or points, can be accounted for, in part, by luck" For example, a player entering the ice seconds before a goal is scored likely had no role in the goal but would receive a + 1 on the plus-minus statistic. Thus, we also assessed PDO, a statistic designed to account for luck, and found no differences between groups across the 3 time windows. Interestingly, nonsignificant interactions occurred for the 5-game (P = .019) and 10game (P = .031) windows, whereby the players with concussion increased their PDO from below to above league average (average = 100) and the control group decreased from above to below league average. These trends were not observed in the full-season analysis (P =.531) and could represent an expected regression to the mean. Taken together, these results suggest no meaningful differences in player performance during the remainder of the season in which the concussion occurred. Yet given the findings of Longstaffe et al,²⁶ future investigators should assess advanced metrics over subsequent seasons to identify potential prolonged deficits, as the effects of concussion may be heightened with age.

Although we selected advanced metrics to find suspected deficits not identified by traditional performance metrics, hundreds of these metrics exist in the sports realm. Therefore, our study was limited to the large number of primary and secondary selected metrics presented here, and different metrics might have produced different outcomes. Furthermore, the players with concussions were identified from public sources, and it is likely that this approach, although previously used by multiple authors, did not detect all concussive events, as underreporting or delayed reporting of concussion is well established.^{33–35} Our primary purpose was to examine the effect of concussion on player performance. Because of uneven positional distributions and oversampling of data, the effect of position was not explored, but no theoretical rationale in the literature suggests that position would be a key confounding variable in performance after concussion. The exclusion criteria eliminated players who did not participate in at least 5 consecutive games postconcussion and those who sustained a subsequent orthopaedic injury; thus, these results may not represent the postconcussion performance of all NHL players or athletes in other sports or at other levels. During the time period of the identified concussions (2008-2015), a substantial societal shift occurred in the awareness and understanding of concussions, including lawsuits by former players against both the National Football League and the NHL, which may have influenced concussion-management decisions during the study time frame. The individual players' concussion histories cannot be reliably identified through public media sources and therefore potential dose-response outcomes (ie, decreased performance after an increased number of prior concussions) could not be assessed. Finally, the theoretical rationale underlying this study, the presence of lingering postconcussion neurologic deficits,^{9,11–14} was identified among high school and collegiate student-athletes. Whether these same deficits are present in professional athletes is unknown.

Our findings suggest that no meaningful ongoing performance deficits were evident in NHL players with concussions over the course of a season, whether assessed in the short, medium, or long term. These results build on the work of researchers^{18,19,21,22,31} who also found no differences in hockey performance postconcussion, which is consistent with National Football League and National Basketball Association studies but differs from both soccer and baseball studies. Future investigators could use a tighter matching protocol, match for time loss to more specifically assess potential differences, and use leaguesanctioned medical records to ensure complete accuracy. Although this information is less publicly available, the performance of collegiate student-athletes could be evaluated, which would be more consistent with the population in whom persistent deficits have been identified.

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SUPPLEMENTAL MATERIAL

Supplemental Tables. Secondary advanced metric variables and operational definitions as well as additional hockey metrics.

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