Journal of Athletic Training 2019;54(5):534–540
doi: 10.4085/1062-6050-218-18
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# Evaluating Performance of National Hockey League Players After a Concussion Versus Lower Body Injury

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***Context:*** Concussions elicit changes in brain function that may extend well beyond clinical symptom recovery. Whether these changes produce meaningful deficits outside the laboratory environment is unclear. The results of player performance postconcussion within professional sports have been mixed.

***Objective:*** To determine whether National Hockey League (NHL) players with concussions performed worse after returning to sport than players with lower body injuries or uninjured players.

***Design:*** Cohort study.

***Setting:*** Publicly available Web sites that compiled injury and player statistics of NHL players.

***Patients or Other Participants:*** Male NHL players who missed games due to a concussion ($n = 22$), lower body injury ($n = 21$), or noninjury (ie, personal reason or season break; $n = 13$) during the 2013–2014 and 2014–2015 regular seasons. Data on concussed athletes were used to identify similar players with lower body injury and noninjury based on (1) position, (2) time loss, (3) time on the ice, and (4) team.

***Main Outcome Measure(s):*** The primary performance metric was a modified plus-minus statistic calculated by weighting the players' plus-minus metric by their team's simple rating system to account for varying team performances. Linear mixed models assessed the relationship between injury type (concussion, lower body, or noninjury) and performance (plus-minus score).

***Results:*** We observed a quadratic effect for a time$^2$ × group interaction ($\chi^2_2 = 8.85$, $P = .01$). This interaction revealed that the concussion and lower body injury groups had similar patterns of an initial decrease (ie, 2 weeks after return to play), followed by an increase in performance compared with the uninjured group in weeks 5 and 6. Meanwhile, the uninjured group had an initial increase in performance. We observed no group × linear time interaction ($P = .47$) or overall group effect ($P = .57$).

***Conclusions:*** The NHL players in the concussion and lower body injury groups displayed similar performance impairments. Both injured cohorts experienced an initial decrease in performance at weeks 1 to 2 after return to play, followed by improved performance at weeks 5 to 6 after return to play, suggesting that the performance implications of concussion may be short lived.

***Key Words:*** mild traumatic brain injuries, orthopaedic injuries, recovery, outcomes, professional athletes

**Key Points**

- Performance did not differ between players with concussion and players with lower body injuries.
- Both concussions and lower body injuries were associated with an initial decrease in performance (weeks 1–2), followed by recovery (weeks 5–6).

Professional athletes across all sports have an overall injury incidence of 2049 injuries per 10 000 athletes.[1] Whereas professional athletes represented less than 1% of all high school athletes,[2] they sustained concussions at 2 to 3 times greater rates than high school or collegiate athletes.[3,4] Among the primary professional sports in the United States, ice hockey[4] and American football[5] had the highest concussion rates. In ice hockey, concussion rates were 6.5 per 1000 player games.[4] Despite the high prevalence of concussion among ice hockey players, most concussion-related research has been focused on football players.

A concussion produces a myriad of physical signs and psychological symptoms resulting from altered brain microstructure and subsequent abnormal function.[6] The clinical presentation of concussion varies, but common symptoms are slowed reaction time, headache, blurred vision, dizziness, sleep problems, subjective memory problems, and other cognitive difficulties.[7] In general, recovery to preinjury levels of functioning is spontaneous, with symptom resolution within days to weeks postinjury.[8] However, authors of recent laboratory studies have indicated that subtle deficits persisted in measures of gait and balance,[9] dynamic motor tasks,[10] working memory,[11] reaction time,[12] visual processing,[13] and cognition,[14] even after concussion-related symptoms resolved.

Movement skill requires the simultaneous execution of cognitive and motor processes that are critical in athletics, and concussion-related decrements in sensory processing,[13] error processing,[15] gait,[9] and attention[16] can potentially disrupt the effective execution of these skills. However, research examining the effects of concussion on subsequent

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athlete performance has generated mixed results. Whereas Wasserman et al[17] reported decreased batting performance after concussion among professional baseball players, no performance decrements were observed among professional American football[18] or ice hockey[19] players in similar post–return-to-play (post-RTP) periods. However, the performance metrics, control groups, and statistical models chosen for analysis likely influenced the heterogeneous results. For instance, not accounting for the level of competition confounds the interpretation of the plus-minus metric when examining professional ice hockey players. Although Kuhn et al[19] selected plus-minus scores, goals, assists, and shots as performance metrics, they averaged performance over time and did not account for the level of competition. Moreover, for all performance studies, the control groups have included players on personal or paternity leave[17,19] or a preperformance-postperformance comparison within the same individual.[18]

The critical question is whether a concussion has a meaningful effect on an athlete's performance due to its effects on the brain. To determine whether concussion affects performance, other confounders must be ruled out. For example, researchers must control for fatigue and loss of fitness due to removal from play. Therefore, players with orthopaedic injuries would be an important comparison group to assess whether concussion differs from any other type of time-loss injury. We wanted to better understand how concussion influenced athlete performance, directly compare players with time lost due to concussion and players with time lost due to lower body injuries or noninjury (eg, personal leave or season break), and account for possible confounding factors (eg, physical condition upon RTP). Therefore, the purpose of our study was to implement a more flexible statistical approach to assess meaningful performance changes post-RTP among National Hockey League (NHL) players after a concussive injury, lower body injury, or noninjury. Our primary hypothesis was that performance would be more impaired post-RTP among players with concussions than among those with lower body injuries or noninjuries. Given the possible persistent changes in gait,[9,10] our secondary hypothesis was that a performance deficit in the concussion group would gradually improve over time but would remain compared with the 2 control groups.

## METHODS

### Identification of Players

For the 2013–2014 and 2014–2015 professional ice hockey seasons, injury and player statistics were compiled from 3 publicly available Web sites: NHL.com (https://www.nhl.com), Rotoworld (https://www.rotoworld.com), and Fox Sports (https://www.foxsports.com). Given the limited injury reporting and availability of data before the 2013 NHL season, only concussions occurring during the 2013–2014 and 2014–2015 seasons were recorded. Players with undisclosed injuries or injuries listed as "head," "neck," or "face" were searched via the same public Web sites to determine if a concussive injury was mentioned. If any of these Web sites listed the player as having a concussion, he was assigned to the concussive group. All players with injuries above the waist, not including concussions, were excluded because concussions could be classified in the general category of *upper body* under the NHL reporting regulations.[20] Goalies were excluded from this analysis because of the limited number of concussions affecting them and their different performance metrics. The study was deemed exempt by the Institutional Review Board at the University of Michigan.

After we identified the concussed cohort, we reviewed the injury log on foxsports.com for each team during the same season to find eligible players. We included 1 to 2 control players for each concussed player; these players were similar to the concussed players and had missed participation due to either a lower body injury or a noninjury (ie, personal reason or season break). The similarity criteria were as follows: (1) player position, (2) time loss, (3) average time on the ice per game for the month preceding time loss (ie, playing time), and (4) team. To facilitate the identification of similar players based on position, we grouped left winger, right winger, and center positions as *forward position* and left and right defensemen as *defense position*. Players were sorted by team and division. Using time loss by the concussed player, a list of players with lower body injuries or noninjuries was generated and sorted by time loss. Players with similar durations of time loss were identified. Athletes were considered to have similar durations of time loss if the difference in total time loss between players was less than 20 days. From the list of players with similar durations of time lost, the average time on the ice for each player was compared to identify athletes who played similar numbers of minutes per game. If a similar player with a lower body injury or noninjury was not identified within the concussed player's division, we expanded the search to the entire NHL within the same season. No control player was included more than once.

Each player with a lower body injury or noninjury listed as the reason for time loss was considered as a possible study participant. Using the criteria described, we selected the best match by identifying a player with the same position, closest time loss, similar time on the ice (playing time), and same team or division as the concussed player, if possible. Identifying players with similar time loss, regardless of injury status, accounted for differences in injury severity. When the exact injury type (eg, ankle sprain, fracture) was not publicly available, we assumed that more severe injuries would have resulted in greater time loss. Therefore, this method minimized the risk of 1 of the injured cohorts having more severe injuries. Players were excluded as possible control participants if they were traded to another team during the season, did not RTP after noninjury, or played during the season break (eg, Olympics). Players were not excluded if the injury occurred within the last 5 to 6 weeks of the season. With our strict criteria, it was not possible to have 1 : 1 : 1 matching. However, each concussed player was paired with at least 1 control player (lower body injury or noninjury).

### Performance

The primary performance outcome of interest was a modified plus-minus statistic. The plus-minus metric gives players a positive point if they are on the ice when their team scores a goal while at even strength or shorthanded and a negative point if they are on the ice when the other

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team scores while at even strength or shorthanded. A lower ranked team is likely to have more goals scored against and fewer goals scored for it than a higher ranked team. For a team sport such as ice hockey, in which 5 other players are on the ice, an individual player's plus-minus score would likely be influenced by the team's overall performance. To account for a team's ranking, an adjusted plus-minus metric was calculated by weighting the player's plus-minus score by his team's simple rating system (SRS), which is a team rating calculated by Hockey Reference (https://www.hockey-reference.com; Sports Reference LLC, Philadelphia, PA). This rating system accounts for the team's difference between goals scored for and against it, along with the strength of its schedule. A positive SRS score indicates a stronger team; a negative SRS score, a weaker team; and a zero SRS score, an average team. The formula for the adjusted plus-minus score follows:

$$\text{Adjusted Plus-Minus Score} = -\text{SRS} \times \text{Plus-Minus Score}.$$

Therefore, the SRS was used to adjust a player's plus-minus score, reweighting a player's plus-minus score by his team's SRS.

## Preinjury–Post-RTP Intervals

We summarized each performance metric from games played by each athlete in 2-week intervals before and after the injury.[17,19] Performance was calculated for the 2 weeks before injury and 2 post-RTP intervals (interval 1 = weeks 1 and 2, interval 2 = weeks 5 and 6). The post-RTP intervals were selected based on the concussion literature, in which researchers have suggested that concussed athletes would RTP after symptoms resolve, typically 7 to 10 days postconcussion,[21] and preliminary evidence[22,23] indicating ongoing brain-function alterations beyond the resolution of clinical symptoms. Therefore, the post-RTP timeframe of weeks 1 and 2 was selected to index the initial performance post-RTP.[22,23] The post-RTP timeframe of weeks 5 and 6 was selected to evaluate whether subclinical alterations persisted beyond the initial RTP.[22,23] Each performance metric was averaged across each 2-week interval. The time was excluded if the athlete played in fewer than 3 games within the 2-week window. Only regular-season games were included in the calculation. Preseason statistics were not included due to inconsistent availability of preseason game logs. Playoff games were also excluded because not all players participated in them.

## Statistical Analysis

To check that our player-identification methods created adequately similar cohorts, we conducted a multivariate analysis of variance comparing our 3 groups for age, height, mass, time in the NHL, time loss, and time on the ice. Linear mixed models assessed the relationship between injury type (concussion, lower body, or noninjury) and performance (ie, plus-minus score). The average time on the ice was used as a playing-time marker. To compare the degree of similarity across groups, we used a Pearson product moment correlation to evaluate time loss and time on the ice.

Authors[18,19] who found no effect of concussion on performance and did not account for between-players differences in performance or individual responses to time loss have used general linear models to evaluate injury-group differences before and after injury. The linear mixed-model approach allows each player to have an individual starting performance, represented by a random intercept, and an individual response to time loss, represented by a random slope. Whereas creating cohorts with similar characteristics is an attempt to account for interindividual differences, it is not possible to account for all individual differences or for all variables that influence performance. Therefore, the linear mixed model accounts for differences in overall performances between players and individual responses to time loss. Moreover, for longitudinal data, linear mixed models are more robust than general linear models when missing data, unequal groups, or varying sample timeframes are present.[24] Unlike a repeated-measures analysis of variance, in which participants are excluded if their data are missing, a mixed model uses all available data. Therefore, we modeled linear mixed models with a random intercept and slope using an unstructured covariance matrix and restricted maximum-likelihood method. To confirm that the random intercept and slope model fit the data appropriately, comparisons of random intercept only, random slope only, and random intercept and slope models were conducted. Next, to test whether injury type (concussion, lower body, noninjury) influenced performance over time, a time $\times$ group interaction was modeled, and linear or quadratic time (time$^2$) effects were compared. The quadratic effect of time produced the best-fit model as measured by comparing –2LogLikelihood ($\chi^2_2 = 8.60$, $P = .01$) and is reported in the "Results."

Model diagnostics and assumptions were assessed by examining the residual plots for homoscedasticity. All analyses were performed in SAS (version 9.4; SAS Institute Inc, Cary, NC), and the $\alpha$ level was set at .05.

## RESULTS

Across the 2013–2014 and 2014–2015 NHL seasons, a total of 56 (n = 30 for 2013–2014 season) players met the inclusion criteria. Of these 56 players, 22 (39%) were concussed, 21 (38%) had lower body injuries, and 13 (23%) had noninjuries. Players had an average of 7.1 $\pm$ 4.0 years of experience at the NHL level. The Pearson product moment correlation for days missed was high between the concussion and lower body injury groups ($r = 0.91$) and the concussed and noninjured groups ($r = 0.85$). The average differences in days missed were 0.73 days between the concussion and lower body injury groups and 3.38 days between the concussion and noninjury groups. The mean difference in time on the ice in the month before time loss was only different between the concussion and noninjury groups ($t_{12} = 4.63$, $P = .001$). The concussion group played, on average, 6.62 more minutes than the noninjury group. The mean difference between the concussion and lower body injury groups and the lower body injury and noninjury groups was less than 30 seconds (both $P > .05$). Using a multivariate analysis of variance, no differences in age, height, mass, time in the NHL, time loss, or time on the ice existed across injury groups ($F_{8,46} = 1.91$; $P = .08$; Table 1).

Of the 22 players in the concussion group, none were missing preinjury data, 4 were missing data for weeks 1 and 2, and 8 were missing data for weeks 5 and 6. Of the 21

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Table 1. Player Demographics by Injury Group

| Characteristic | Overall (n = 56) | Group: Concussion (n = 22) | Lower Body Injury (n = 21) | Noninjury (n = 13) |
|---|---|---|---|---|
| | Mean ± SD | | | |
| Age, y | 29.2 ± 3.8 | 28.7 ± 3.9 | 29.2 ± 3.2 | 30.2 ± 4.4 |
| Height, cm | 185.2 ± 6.1 | 185.9 ± 7.1 | 185.7 ± 6.1 | 182.9 ± 3.8 |
| Mass, kg | 91.8 ± 7.3 | 92.1 ± 6.7 | 94.0 ± 9.0 | 88.0 ± 7.7 |
| Time in National Hockey League, y | 7.1 ± 4.0 | 7.4 ± 3.7 | 6.6 ± 3.0 | 7.5 ± 5.7 |
| Time loss from play, d | 18.7 ± 12.4 | 20.9 ± 12.2 | 20.5 ± 14.9 | 12.1 ± 4.9 |
| | No. (%) | | | |
| Position | | | | |
| Forward | 34 (61) | 12 (55) | 12 (57) | 10 (77) |
| Defense | 22 (39) | 10 (45) | 9 (43) | 3 (23) |

players with lower body injuries, 2 were missing preinjury data, none were missing data for weeks 1 and 2, and 5 were missing data for weeks 5 and 6. Of the 13 players in the noninjury group, none were missing preinjury data, 2 were missing data for weeks 1 and 2, and 1 was missing data for weeks 5 and 6. Given that the linear mixed model is robust for missing data, no players were excluded for missing data, and all data points were used in the analysis.

The null model likelihood ratio test of the linear mixed model for adjusted plus-minus score indicated that the model was a stronger estimate of adjusted plus-minus score than the null model ($\chi^2_3 = 11.00$, $P = .01$). Type 3 fixed effects showed main effects of injury, injury × time, and injury × time$^2$ (Table 2).

The differences between groups did not remain constant over time, with a quadratic effect that was different ($\chi^2_2 = 8.85$, $P = .01$). This quadratic effect showed that both the concussion ($t_{36} = 2.65$, $P = .01$) and lower body injury ($t_{36} = 2.65$, $P = .01$) groups experienced an initial post-RTP decrease, followed by an increase during weeks 5 and 6 in adjusted plus-minus performance after their RTP when compared with the noninjury group. We observed no difference in recovery of adjusted plus-minus performance between the concussion and lower body injury groups ($t_{36} = 0.02$, $P = .98$). Therefore, the model indicated that the concussion and lower body injury groups had a U-shaped response to injury, whereas the noninjury group had an inverted-U response (Figure).

In a separate model to test the linear effect, we observed no group × time interaction ($P = .47$). Moreover, for the overall group effect model, no effect of group was present ($P = .57$). Therefore, the injury groups were not different from one another, and no linear effect of time was present.

## DISCUSSION

Our results demonstrated that the concussion group experienced performance decrements post-RTP that were similar to those of the lower body injury group, whereas the noninjury group did not experience an initial decline in performance. Our findings expand on previous work[17,19] in which researchers examined concussion and subsequent athletic performance. Moreover, they add to the literature because we included 2 comparison groups to assess whether a concussion-specific effect or general injury effect on performance was present. Contrary to the findings of Kuhn et al,[19] who demonstrated that concussive injury was not associated with decreased NHL player performance when evaluated at 5 games post-RTP, we observed that player performance decreased from preinjury to weeks 1 and 2 post-RTP. Performance then increased by weeks 5 and 6 post-RTP to preinjury levels. However, this pattern of an initial decrease in performance followed by an increase was not different between the concussion and lower body injury groups. Whereas Kuhn et al[19] examined plus-minus scores, goals, assists, and shots as performance metrics, they averaged performance over time and did not account

Table 2. Linear Mixed Model for Adjusted Plus-Minus Score: Unstructured Covariance Matrix

| Effect[a,b] | Group | Estimate | 95% Confidence Interval | Standard Error | *P* Value |
|---|---|---|---|---|---|
| Intercept | | −1.55 | −2.83, −0.27 | 0.64 | .02 |
| Injury | Concussion | 2.42 | 0.77, 4.08 | 0.82 | .005 |
| | Lower body injury | 2.20 | 0.56, 3.84 | 0.81 | .01 |
| | Noninjury | Reference | | | |
| Time | | 0.98 | 0.09, 1.88 | 0.44 | .03 |
| Injury × time | Concussion | −1.60 | −2.76, −0.44 | 0.57 | .008 |
| | Lower body injury | −1.53 | −2.67, −0.39 | 0.56 | .01 |
| | Noninjury | Reference | | | |
| Time$^2$ | | −0.16 | −0.31, −0.01 | 0.07 | .04 |
| Injury × time$^2$ | Concussion | 0.25 | 0.06, 0.45 | 0.10 | .01 |
| | Lower body injury | 0.25 | 0.06, 0.44 | 0.09 | .01 |
| | Noninjury | Reference | | | |

[a] Time reflects the linear effect of time, which tests whether performance continued to increase or decrease.
[b] Time$^2$ reflects the quadratic effect of time, which tests whether performance initially changed but then returned to baseline.



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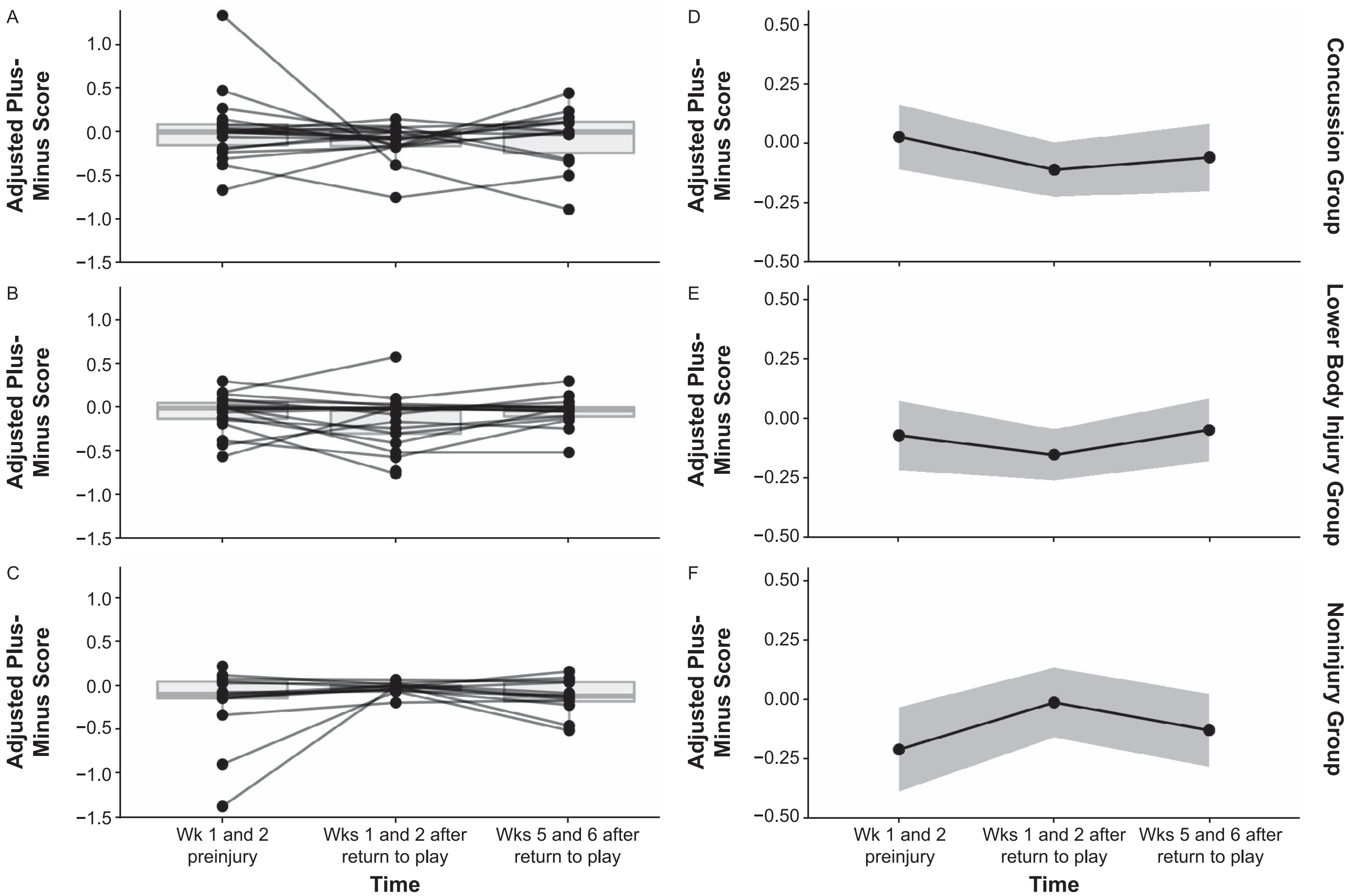


**Figure. Raw and model-predicted adjusted plus-minus scores over time. A–C), Raw adjusted plus-minus scores over time for each individual depicted with each line and dot. The boxplots summarize the adjusted plus-minus scores at each time point across all players. D–F), Model-predicted adjusted plus-minus scores depict the model-predicted results and 95% confidence intervals.**

for competition level. We also accounted for opponent level and used mixed models, making the design more robust and more sensitive to changes in performance over time.

Navarro et al[25] reported decreased NHL player performance in the season after concussion. However, their control group was a mix of athletes who were either uninjured or had other types of injuries, and they were unable to address whether concussion was associated with worse performance than other injury types.[25] Among professional baseball players, Wasserman et al[17] noted initially decreased batting performance postconcussion. Although they and we found initial decrements in performance, we saw no greater impairment in the concussion than in the lower body injury group. Injury may be associated with changes in performance initially after a player's RTP, but concussion did not appear to have a greater effect on performance. Wasserman et al[17] indicated that concussion may affect performance due to persistent impairments in reaction time, visuomotor coordination, decision making, or visual tracking. When a lower body injury group is included for comparison, the concussion group appears to display a performance decrement similar to but not greater than that of the lower body injury group. Consequently, the mechanisms of these deficits may be similar, such as fatigue after removal from play, or different, such as more "top-down" cognitive concerns (eg, difficulty concentrating, slow reaction time) after a concussion leading to impaired performance relative to more "bottom-up" biomechanical concerns (eg, joint instability, pain) after a lower body injury. Researchers should include cognitive and biomechanical assessments to elucidate the causes of decreased performance after a concussion or lower body injury. These findings would inform rehabilitation and athlete care to limit post-RTP performance decrements.

Preliminary evidence has shown that concussion-related deficits might be due to ongoing cognitive problems. Outside of sport performance, researchers[16,26–28] have demonstrated ongoing cognitive deficits at the time when an athlete would RTP. For example, in a sample of collegiate American football athletes, McCrea et al[21] reported that up to 16% of asymptomatic athletes demonstrated abnormal neurocognitive performance. Advanced imaging has enabled more sensitive detection of perturbed brain function, whereby functional magnetic resonance imaging has demonstrated differences in the brain-activation patterns of concussed athletes compared with control participants, even when they were asymptomatic.[28] Brain metabolism has been shown to be perturbed for up to 30 days postinjury,[22,23] well beyond the point at which concussed individuals have returned to premorbid levels of functioning.[21] Cremona-Meteyard and Geffen[27] described greater visual-spatial reaction time among rugby players up to a year postinjury, indicating impaired visual attention. Using electroencephalography,



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investigators have detected attention-related deficits up to 30 years postinjury,[16,26] along with slower movement,[26] among an otherwise healthy sample. Collectively, the evidence has indicated that clinical resolution of symptoms may not represent true brain recovery postinjury.[23,26] Reassuringly, if we assume our concussion group had prolonged physiological brain changes[22,23] and slowed reaction time[27] beyond 30 days postconcussion, it does not appear that those changes had a meaningful effect greater than a general injury effect on ice hockey players' performance.

Whereas we demonstrated an initial decline in performance postconcussion, we also observed this decline in players with lower body injuries. Therefore, it is unclear whether the initial declines that the concussed players experienced were concussion specific or related to general injury factors (eg, loss of physical conditioning). We could not determine the exact causes of the initial performance declines; however, given the different origins of the injuries (brain versus lower body), it is biologically plausible that the physiological drivers of decreased performance were different. However, our analysis indicated that brain and lower body injuries did not generate performance deficits of different magnitudes.

Our work was not designed to elucidate the biological underpinnings of performance decline, but persistent deficits in the domains of reaction time,[27] gait,[9] and decision making[16] have been reported postconcussion. Both the concussion and lower body injury groups experienced initial decreases in performance, yet the mechanisms for these declines might have been different. Decreases in performance among concussed players might be due to more cognitive impairments, and decreased performance after lower body injury might be due to neuromuscular mechanisms or deconditioning if the time missed from participation is longer than that of concussed players. Given that the number of days missed from participation was not different between the concussion and lower body injury groups, it is not likely that athlete fitness was a factor. Moreover, we did not observe a difference in post-RTP time on the ice among groups. Therefore, the concussion, lower body injury, and noninjury groups had similar amounts of playing time at weeks 1 and 2 post-RTP and weeks 5 and 6 post-RTP. The concussion and lower body injury groups were injured for similar durations, and post-RTP performance did not differ between the 2 injured cohorts. Researchers should assess whether the initial decrements in performance are due to similar mechanisms among individuals who sustained concussions and those who sustained lower body injuries.

## LIMITATIONS

The main limitation of our analysis was the identification of players with concussive injuries from publicly available databases. Medical records were not used to identify concussed players, and relying on publicly available data may have yielded an incomplete list of concussed athletes. However, by scanning multiple public resources for reports of concussion and reviewing each player with a classified head injury, it is likely that a list of most of the concussive injuries was generated. Given that this list was not exhaustive and did not include injuries before 2013 because few injury reports were available, we evaluated only incident concussions and did not account for previous concussions. Athletes with a concussion history are more likely to experience a recurrent concussion during their playing careers.[29] With increasing numbers of concussions, an athlete usually experiences prolonged recovery time and more severe deficits.[30] Without accounting for previous concussive injuries, it remains unclear whether multiple concussive injuries drive the relationship between concussion and athletic performance. Moreover, by eliminating upper body injuries from the analysis, we eliminated the chance of a concussion being misclassified as an *upper body orthopaedic injury*. Lower body injuries are the most common musculoskeletal injuries in ice hockey,[13] so limiting the orthopaedic injury group to lower body injuries made that group more homogeneous while it continued to represent NHL orthopaedic injuries. Finally, classifying a concussive injury as an *upper body injury* may result in underreporting[31] or missing these injuries, which would also limit our ability to assess all concussive injuries. Yet the development of the NHL concussion protocol means that more players with concussions are likely being identified. Injuries other than concussions may also have been missed. Whereas we screened for other injuries occurring during our study's timeframe, it is possible that other injuries were not reported and, thus, not captured in our analysis. In future studies, researchers should try to use the NHL injury-surveillance system to identify specific injuries.

The initial decrease in adjusted plus-minus rating after concussive or lower body injury indicated that players were on the ice for more goals scored against than for their teams. Given that the adjusted plus-minus metric accounted for team rank, the decrease in performance was not attributable to their team's rank relative to their opponent's rank. Differences in team styles of play and systems might yield more or less success against other teams, but this would be difficult to objectively quantify. Although some teams may match up well against each other due to the systems they use, other factors, such as how well the goalie is playing, make it difficult to quantify the effectiveness of that team's system or style of play. We were unable to assess each team's style of play and success against another team's style of play, but the adjusted plus-minus metric should have accounted for a team's overall success.

Additional limitations of using publicly available data were the inability to assess whether an athlete's playing time was restricted post-RTP or whether players were placed on different line pairings, which could have positively or negatively influenced player performance. Because both playing time and line pairing could conceivably influence the adjusted plus-minus rating, our results might be biased. However, we have no reason to believe that the portion of players who were restricted or changed line pairings was different between the concussion and lower body injury cohorts. Therefore, even though the possibility of bias exists, we expect the level was low and further emphasize the importance of including the lower body injury cohort for comparison.

Lastly, the adjusted plus-minus metric may not be sensitive enough to detect performance deficits. Given that scoring is the basis of the plus-minus metric and scoring reflects multiple performances by the individual player, opponent, goaltender, and possibly nonperformance-related factors (eg, video review), the adjusted plus-minus metric

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may not detect more subtle changes in an individual's performance. A more sensitive metric for forwards may be the shooting percentage, which represents the number of goals scored relative to the total number of shots taken. Nevertheless, shooting percentage was not available at the time of data extraction and we were unable to assess this metric.

## CONCLUSIONS

Our results extend previous research in which investigators examined the effects of concussion on professional athlete performance. We found no specific effect of concussion on performance, meaning that no difference in player performance existed after a player sustained a concussion or a lower body injury. Therefore, the initial changes in performance were due to any injury and not specific to concussion. Moreover, any initial decline in performance was temporary and resolved within 5 to 6 weeks of returning to play.

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