Situational Factors Impacting Severe Concussions in Professional Hockey

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Abstract

The following honours thesis compiles a dataset of reported concussions in the National Hockey League for the 2014-2015, 2015-2016, and 2016-2017 seasons. The main purpose of the thesis is data collection for a further statistical study using survival analysis. Each concussion event is observed on video, and the presence of 16 independent, situational factors is recorded. Relevant situational factors are determined through medical analysis of concussion, and interviews with former National Hockey League players. The length of each observed concussion is recorded to provide a measure of concussion severity. Concussion severity is divided into nine levels, and Chi – square tests of independence are conducted to determine whether statistically significant relationships exist between the independent, situational factors, and concussion severity. The independent, situational factors of location of body contact, legality of body contact, and recurrent concussion are all determined as significantly related to concussion severity. Further experimental analysis reveals a potential relationship between puck possession and severe concussion. Hit velocity is then identified as a variable that interacts with the independent, situational factors to further impact concussion severity. An expansion of the honours thesis in collaboration with Atul Dar and Yigit Aydede is ultimately outlined.

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I. Introduction

Over recent years, similar to other contact sports, the regularity of concussions in professional hockey has risen dramatically (Tator & Wennberg, 2008). Due to the sharp increase in the public's awareness of sports-related concussions, research has been devoted to the long-term effects of concussions and repeated head trauma (Thompson, 2015). Recently, the VA-BU-CLF Brain bank diagnosed 87 of 91 brains from former NFL players with Chronic Traumatic Encephalopathy (Concussion Legacy Foundation, 2016). Since 2011, numerous former professional hockey players have passed away due to complications with depression, and many were diagnosed with CTE following their deaths (Fitz-Gerald, 2015). These former NHL players include Reggie Fleming, Bob Probert, and Derek Boogard (Fitz-Gerald, 2015).

While information is increasing about the health concerns associated with concussions, a lack of information exists about the situational factors that lead to concussion. In hockey, many antecedent conditions exist prior to an observed concussion, conditions that have the potential to impact the severity of the concussion. In hockey, if a relationship exists between certain situational factors observed before a concussion and the concussion's severity, then preventative measures can be created to eliminate severe concussions from the sport. The objective of my research is to build the first large-scale dataset of observed concussions in the NHL that can ultimately be used to predict the probability of, and recovery from, severe concussions.

II. Literature Review

In preparation for conducting research to determine the situational factors that lead to severe concussions in hockey, previous studies on concussions in professional and amateur hockey were analyzed. In *National Hockey League Reported Concussions, 1986-87 to 2001-02*, R.A Wennberg and C.H. Tator (2003) found a significant increase in the reported concussion rate from 1986 to 2002. In the 1986-87 NHL season, only seven concussions were reported, while in the 2001-2002 NHL season, 62 concussions were reported (Tator & Wennberg, 2003). In an additional study, Tator and Wennberg (2008) found that from 2002 to 2008 in the NHL, the mean reported concussions per season was 64. While Tator and Wennberg (2003 & 2008) provided an interesting picture on the rate of reported concussions in the NHL, they did not conduct any research on the causes of concussions in hockey.

Other relevant articles studying concussions in professional and amateur hockey include *Descriptive Epidemiology of Collegiate Men's Ice Hockey Injuries* (Agel, Dompier, Dick, & Marshall, 2007), *Predictors of Injury in Ice Hockey Players* (Smith, Stuart, Wiese-Bjornstal, & Gunnon, 1997), *The Impact of Face Shield use on Concussions in ice Hockey* (Benson, Rose, & Meeuwisse, 2002), *The effect of Visors on Head and Facial Injury in National Hockey League Players* (Stevens, Lassonde, Beaumont, & Keenan, 2006), and *Concussions in Hockey: There is Cause for Concern* (Goodman, Gaetz, & Meichenbaum, 2001). While Stevens et al. (2006) and Smith et al. (1997) both analyzed certain conditions that lead to injuries in hockey, neither study analyzed conditions that led to specifically concussions. Stevens et al. (2006) and Smith et al. (1997) were instead concerned with injuries other than concussions. While Benson et al. (2002) analyzed how the use of protective face shields can reduce concussion severity in hockey, they did not use any statistical regression analysis in their methods. Instead, Benson et al. (2002) reported the proportions of severe and non-severe concussions observed by players wearing protective face shields. Similar to Benson et al. (2002), Goodman et al. (2001) did not conduct any statistical regression in their study of concussions in hockey. Instead, Goodman et al. (2001) were concerned with finding differences between the rates of concussions observed in practices compared to games, and by offensive players compared to defensive players. Goodman et al. (2001) did, however, find that the majority of concussions in their study were caused by contact with the boards or ice. Finally, Agel et al. (1997) used video of National Collegiate Athletic Association hockey games to describe situational factors of injuries in hockey. However, Agel et al. (1997) did not focus specifically on concussions, and they simply reported proportions rather than conduct statistical analysis.

The two prior studies most relevant to my research question are, *A Prospective Study of Concussions Among National Hockey League Players During Regular Season Games: The NHL – NHLPA Concussion Program* (Benson, Meeuwisse, Rizos, Kang, & Burke, 2011) and *A Systematic Video Analysis of National Hockey League (NHL) Concussions* (Hutchison, Echemendia, Meeuwisse, & Comper, 2013). Using standardized injury report forms submitted by every NHL team, Benson et al. (2011) isolated all reported NHL concussions from 1997 to 2004, and analyzed said concussions for their severity. In the study, a concussion was considered severe if it resulted in time loss of greater than ten days (Benson et. al, 2011). Using a univariable logistic regression, independent variables of "age, position, recurrent concussion during the study period, and initial postconcussion symptoms, signs, and neurological examination findings" (Benson et al., 2011, p. 2) were used to predict the dependent variable of severe concussion. The dependent variable was coded 1 for severe concussions (time loss > 10 days), and 0 for non-severe concussions (Benson et al., 2011). Following their analysis, Benson et al. (2011) found that significant predictors of severe concussions were recurrent concussion and post concussion symptoms of light sensitivity, fatigue, consciousness loss, and headache.

Unlike Benson et al. (2011) who used standardized written injury reports; Hutchison et al. (2013) used video records of reported NHL concussions to record certain antecedent conditions that are present prior to an observed concussion. Hutchison et al. (2013) conducted their study using the Heads Up Checklist, a standardized checklist of certain situational factors that are predicted to lead to concussion (Hutchison, Echemendia, Meeuwisse, & Comper, 2013). Similar to the majority of other previous studies conducted on concussions in hockey, Hutchison et al. (2013) reported only observed proportions rather than using statistical modeling.

While the studies conducted by Benson et al. (2011) and Hutchison et al. (2013) both used unique methods of determining the predictors of concussions in hockey, both studies can certainly be improved upon. For example, while they used an effective data source, Hutchison et al. (2013) did not use any models that can statistically determine the predictors of concussions in hockey. Although Benson et al. (2011) used statistical modeling to determine predictors of severe concussion in hockey, the specific modeling and methods used are not the optimal way of capturing the relationship. Benson et al. (2011) used standardized injury report forms submitted by individual team's trainers as the data source in the study, and were dependent on the successful and honest reporting of concussions by each individual trainer. One could surely imagine the scenario in which an individual trainer incorrectly completed a standardized injury report, and therefore, the results found by Benson et al. (2011) may not be reliable. Additionally, Benson et al. (2011) used a univariable logistic regression, meaning that the only two outcomes for the dependent variable were 0 for a "non-severe" concussion, and 1 for a "severe" concussion. Based on the definition of variables in the study, a severe concussion was one that resulted in time loss of greater than 10 days (Benson et al., 2011). Clearly a concussion that results in time loss of 25 days is more severe than a concussion that results in time loss of 11 days. However, because their model defined a severe concussion as one that resulted in time loss of greater than ten days, Benson et al. (2011) were unable to capture the difference in severity between two concussions resulting in time loss of 11 and 25 days respectively.

III. Analysis & Reasoning

In hockey, the majority of injuries are observed when body contact occurs between two players (Agel et al., 2007). Therefore, for my research, I am concerned only with concussions that were the result of body contact. In developing my reasoning prior to conducting research, I needed to determine specific situational factors present during an observed concussion that were likely to increase or decrease the severity of the observed concussion. Because no theory exists to help explain the predictors of severe concussions in contact sports, I needed an alternative way to develop reasoning for using specific situational factors that would be significantly related to severe concussions in hockey. To establish the independent situational factors that would be related to severe concussions in hockey, I analyzed the Heads Up Checklist proposed by Hutchison et al. (2013), as well as additional medical reasoning behind concussions. Along with a medical examination of concussions, I interviewed former professional hockey players with histories of concussions to gather their own personal opinions on the situational factors present during an observed concussion that might be related to the concussion's severity.

The Heads Up Checklist is a standardized, observational method to record the conditions present prior to an observed concussion in hockey (Hutchison et al., 2013). The Heads Up Checklist includes seventeen situational factors of interest when observing a concussion in hockey (Hutchison et al., 2013). Certain antecedent factors included in the Heads Up Checklist that I considered relevant for my research include the body part from another player in which the injured player was contacted by, the principal point of contact on the injured player, the use of a visor by the injured player, anticipation of contact by the injured player, puck possession of the injured player, the zone and relative location of the event, the game situation, and the legality of the contact (Hutchison et al., 2013). For my research, a total of eleven independent situational factors were selected based on my analysis of the Heads Up Checklist. These factors are:

1. **Body Contact:** With opponent or not
2. **Contacted By (Other player):** Stick, skate, head, gloves, elbow, shoulder, torso, or lower body
3. **Principal Point of Contact:** Head, shoulder, elbow, torso, or lower body
4. **Visor Use:** Yes or no
5. **Zone:** Offensive, defensive, or neutral
6. **Location:** Open ice or along the boards
7. **Puck Possession:** Yes, no, or just released
8. **Anticipation of Contact:** Yes or no

9. **Legality of Contact:** Legal or illegal

10. **Time:** 1st period, 2nd period, 3rd period, or overtime

11. **Score Discrepancy (Relative to Injured Player):** Winning, losing, or tied

While the listed independent factors may not be exact replicas to those on the Heads Up Checklist, they were modified only slightly in order to increase the ease and clarity in which they could be recorded and implemented into a statistical model.

According to Edwards and Bodle (2014), the causes of concussions are complicated, and extend beyond the initial impact to the head. Concussions are caused by a combination of "rapid acceleration and deceleration forces applied to the moving brain" (Edwards & Bodle, 2014, p. 129). Upon impact to the head, the brain decelerates and slows behind initial head movement, followed by a rapid acceleration in which the brain crashes into the wall of the skull (Edwards & Bodle, 2014, p. 129). The concussion's severity is increased when a "whiplash" movement is created, as the "rotation of the head adds to the shearing forces and distortion of vascular and neural elements in the brain" (Edwards & Bodle, 2014, p. 129). In hockey, the "whiplash" movement of the head often occurs when a player is not anticipating body contact to occur (K. Lockett, personal communication, December 4). I therefore determined that the independent situational factor "anticipation of contact" is likely to be significantly related to severe concussion, as the "whiplash" motion is likely to occur when contact is not anticipated.

In developing my final list of independent variables, I spent several hours discussing my research objective with three former NHL players: Ken Lockett, Dave Gorman, and Mike Dwyer. Lockett, Gorman, and Dwyer, all with a history of concussions, played hockey professionally between the years 1967-1979, 1976-1983, and 1972-1982 respectively. All three former professionals agreed that the 11 previously mentioned independent situational factors should be related to decreases or increases in concussion severity (K. Lockett, D. Gorman, & M. Dwyer, personal communication, December 4, 2016). After my discussion with Lockett, Gorman, and Dwyer, I decided to add five additional independent situational factors to my research. Lockett, Gorman, and Dwyer all firmly believed that recurrent concussions are more severe than initial concussions, and that injured players who do not immediately leave the game following the concussion suffer more severe concussions (K. Lockett, D. Gorman, & M. Dwyer, personal communication, December 4, 2016). In hockey, players are revered for their toughness and durability, and as a result, players often try to continue playing through injuries. Lockett, Gorman, and Dwyer claimed that this mentality could lead to concussed players trying to remain in the game following the injury (December 4, 2016). Additionally, the three former professionals claimed that the scheduling of NHL games could have an impact on the incidence of concussion and concussion severity (K. Lockett, D. Gorman, & M. Dwyer, personal communication, December 4, 2016). For example, Lockett believed that players are often tired and impaired during the second game of games scheduled on consecutive nights, while Gorman claimed that more severe injuries tend to occur during the latter stages of the NHL season (K. Lockett, & D. Gorman, personal communication, December 4, 2016). A final piece of insight that I gathered from my personal communications with former professional hockey players involved the secondary contact of an observed incident. All three former professionals agreed that concussion severity should increase if the observed hit involved both principal, and secondary contact to the head (K. Lockett, D. Gorman, & M. Dwyer, personal communication, December 4, 2016). For example, if a player's head makes secondary contact to the boards or ice following body contact, then the resulting concussion could be more severe. After my discussion with the three former professional hockey players, I decided to add the following independent factors to the previously mentioned 11 independent factors:

1. **Second Game of Two Consecutive Games:** Yes or no
2. **Game Number:** Relative to the start of the season
3. **Left Game:** Yes or no
4. **Secondary Contact:** Head onto ice, boards, glass, post or none
5. **Recurrent Concussion:** 1^{st} concussion, 2^{nd} concussion, 3^{rd} concussion, etc.

IV. Data Sources & Research Methods

Similar to Hutchison et al. (2013), I use video data of NHL games in order to determine predictors of severe concussions. Video of NHL games was obtained through a subscription to Rogers NHL GameCentre Live. I observe reported concussions in the NHL for the 2014-2015, 2015-2016, and 2016-2017 seasons, and record the presence of each of my 16 independent, situational factors. I use the NHL Injury Report from Fox Sports to determine the date in which a player experiences a concussion. Afterwards, I track each concussed player on Rotoworld, a fantasy hockey website that consolidates news clippings for all NHL players. The news clippings from Rotoworld allow me to determine the specific moment in the game in which the individual experiences a concussion, and the date in which the individual returns to play. The NHL Injury Report from Fox Sports, along with the news clippings from Rotoworld, allow me to determine where I can find each reported concussion in my video database, as well as the length of each reported concussion.

VI. Results & Limitations

A total of 106 concussions are observed, dating from October 5th, 2014, to March 6th, 2017. Five observations are omitted, as the observed concussions are not the result of body contact. Four of the omitted concussions are the result of contact of the puck with the head, while the other is the result of a fistfight. The mean days injured is approximately 31.21, while the mean game number relative to the start of the season is approximately 42.26 days. I observe a total of 37 players who were injured for ten days or less, and a total of 12 players who were injured for 50 days or more. The sample includes six players who have not returned to play to date. The frequency distribution is as follows:

Days Injured	**Frequency**
0 – 10	37
11 – 20	31
21 – 30	9
31 – 40	7
41 – 50	5
51 – 60	12
61 – 70	1
71 – 80	1
81 – 90	1
> 90	8

Figure 1: Frequency Distribution of Days Injured

Of the 101 observed concussions, 19 are recurrent. Approximately 49% of observed concussions in the sample are caused by illegal hits, thus implying no real difference between the incidences of concussions caused by illegal or legal hits. Additionally, no difference appears to exist between the incidences of concussions caused by non-anticipated versus anticipated hits, hits in the open ice versus along the boards, or hits with no secondary contact of the head versus secondary contact of the head with the boards, glass, post, or ice. Approximately 49% of observed concussions in the sample are the result of a non-anticipated hit, 52% the result of an open ice hit, and 52% the result of a hit with secondary contact of the head. A difference does appear to exist between incidences of concussions caused by different principal points of contact. Of the principal points of contact existent in the sample (elbow, head, shoulder, torso, lower body, none), principal point of contact with the head is evident in approximately 65% of observed concussions.

Total Observations	106
Observations Used	101
Mean Days Injured	31.21
Mean Game Number	42.26
Proportion of Illegal Hits	51%
Proportion of Legal Hits	49%
Proportion of Concussions in Consecutive Games	18%
Proportion of Injured Players that Left Game	81%
Number of Recurrent Concussions	19
Proportion of Concussions in 1st Period	35%

Proportion of Concussions in 2nd Period	44%
Proportion of Concussions in 3rd Period	21%
Proportion of hits Anticipated	51%
Puck Possession: Proportion of Concussions	20.79%
Just Released: Proportion of Concussions	39.60%
No Possession: Proportion of Concussions	39.6%
Open Ice: Proportion of Concussions	52%
Along the Boards: Proportion of Concussions	48%
Neutral Zone: Proportion of Concussions	19.8%
Defensive Zone: Proportion of Concussions	47.52%
Offensive Zone: Proportion of Concussions	32.67%
Secondary Contact of Head: Proportion of Concussions	52%
Principal Point of Contact with Head: Proportion of Concussions	65%

Figure 2: Summary Sample Statistics

One limitation of the dataset is caused by the six players who have not returned to play since experiencing their most recent concussion. During my research, uncertainty arose in how the dependent variable should be listed for these players. For example, perhaps Ryan Clowe, who has not returned from a concussion suffered on November 6th 2014, should not be treated the same as Clarke MacArthur, who has not returned from a concussion suffered on September 26th, 2016. However, if Ryan Clowe were to be recorded as being injured for 886 days (November 6th, 2014 – April 10th, 2017), the mean days injured would be impacted so that it would not accurately reflect the information in the sample. For the purpose of calculating the mean days injured in the sample, the six players are recorded as being injured for 200 days. The ceiling of 200 days injured is chosen for the six unreturned players because doing so places them above the previous lengthiest observed concussion of 188 days, without inappropriately raising the sample mean. A further limitation to the dataset in its present form arises from its inability to consider the velocity associated with each observed incident. One could certainly infer that the velocity of each hit associated with an observed concussion could have a significant impact on the concussion's severity. By controlling for velocity, perhaps the independent variables listed in the dataset would show more significant relationships with concussion severity.

In order to determine statistical relationships between situational factors present at an observed concussion, and concussion severity, I, like Benson et al. (2011), treat concussion severity as categorical. However, unlike Benson et al. (2011), I divide concussion severity into several different levels. By adding multiple levels for concussion severity, I am more accurately able to consider the differing severity of concussions lasting 10 days, 25 days, 40 days, etc. I capture 10 different levels of concussion severity by dividing days injured into the following categories:

1. **0 – 10 days:** Recorded as 0
2. **11 – 20 days:** Recorded as 1
3. **21 – 30 days:** Recorded as 2
4. **31 – 40 days:** Recorded as 3
5. **41 – 50 days:** Recorded as 4
6. **51 – 60 days:** Recorded as 5

7. **61 – 70 days:** Recorded as 6
8. **71 – 80 days:** Recorded as 7
9. **81 – 90 days:** Recorded as 8
10. **>90 days:** Recorded as 9

By dividing concussion severity into several categories, I am able to conduct Chi – square tests of independence to determine whether significant relationships exist between my independent factors and concussion severity (McHugh, 2013). After conducting Chi – square tests of independence for all of my independent factors and concussion severity, I am able to determine that the factors location, legality of contact, and recurrent concussion are all significantly related to concussion severity. Location of the observed concussion is significantly related to concussion severity at the ten percent level, legality of contact is significantly related to concussion severity at the five percent level, and recurrent concussion is significantly related to concussion severity at all levels.

	Location		
Days Injured	**Boards**	**Open Ice**	**Total**
0 - 10	13	24	**37**
11 - 20	15	16	**31**
21 - 30	7	2	**9**
31 - 40	2	5	**7**
41 - 50	5	0	**5**
51 - 60	0	1	**1**
61 - 70	0	1	**1**
71 - 80	1	0	**1**
81 - 90	1	0	**1**
>91	4	4	**8**
Total	**48**	**53**	**101**

Pearson Chi - Square (9) = 16.1581
Pr = 0.064

Figure 3: Chi – Square Test of Independence (Days Injured & Location)

Days Injured	Legality: Legal	Illegal	Total
0 - 10	22	15	37
11 - 20	21	10	31
21 - 30	2	7	9
31 - 40	4	3	7
41 - 50	1	4	5
51 - 60	0	1	1
61 - 70	0	1	1
71 - 80	0	1	1
81 - 90	1	0	1
>91	1	7	8
Total	**52**	**49**	**101**

Pearson Chi - Square (9) = 18.3753
Pr = 0.031

Figure 4: Chi – Square Test of Independence (Days Injured & Legality of Contact)

Days Injured	Recurrent Concussion: 1st Conc.	2nd Conc.	3rd Conc.	4th Conc.	Total
0 - 10	34	3	0	0	37
11 - 20	27	3	1	0	31
21 - 30	8	1	0	0	9
31 - 40	6	1	0	0	7
41 - 50	2	2	1	0	5
51 - 60	1	0	0	0	1
61 - 70	0	1	0	0	1
71 - 80	1	0	0	0	1
81 - 90	1	0	0	0	1
>91	2	1	4	1	8
Total	**82**	**12**	**6**	**1**	**101**

Pearson Chi - Square (9) = 59.8690
Pr = 0.000

Figure 5: Chi – Square Test of Independence (Days Injured & Recurrent Concussion)

Interestingly, as observed in the sample, the factors location, legality, and recurrent have no real impact on the incidence of concussion. However, recurrent concussions, concussions received along the boards, and concussions received by illegal body contact all significantly increase concussion severity. Therefore, while the location of an observed concussion, the legality of an observed concussion, or the recurrence of an observed concussion may not impact the number of concussions observed in the NHL, they certainly impact the severity of concussions observed in the NHL.

V. Experimental Analysis

As the primary goal of my thesis is to collect data for use in a future study, no detailed empirical analysis is conducted. However, after identifying statistically significant relationships between concussion severity and location of concussion, legality of contact, and recurrent concussion, I conduct an experimental logistic regression to identify further potential significant relationships between situational factors and concussion severity. For the purpose of conducting a simple logistic regression, the dependent variable of severe concussion is developed. A concussion is considered severe, and coded 1 in the analysis, if it results in time loss of over 21 days. A concussion is considered not severe, and coded 0 in the analysis, if it results in time loss of less than or equal to 21 days. I am therefore able to use my data to conduct a simple logistic regression in Stata. After conducting the regression, I find statistically significant relationships at the five percent level between concussion severity and recurrent concussion, legality of contact, and puck possession. Recurrent concussion and legality of contact both have positive signs, indicating that the likelihood of a severe concussion is predicted to increase from a recurrent concussion or a concussion received from illegal contact. Puck possession, along with just released possession, both have negative signs, indicating that the likelihood of a severe concussion is predicted to decrease from a concussion received when in possession of or, just released, the puck. Therefore, along with the previously identified significant situational factors, puck possession appears to be an additional potential significant situational predictor of severe concussions.

V. Conclusion & Further Research

The results found in my research study have important implications for player safety in the NHL. The determination of significant relationships between concussion severity and certain situational factors present at the time of concussion provides a useful tool for rule makers in the NHL. Because the location on the ice of an observed concussion can significantly impact concussion severity, perhaps the NHL should adjust its body contact rules so that less contact occurs along the boards. Since concussion severity increases from illegal body contact, the NHL must be more diligent in penalizing players that perform illegal hits. By significantly penalizing players who perform illegal hits with lengthy suspensions, the NHL can hopefully deter these players from performing illegal hits, and ultimately reduce the severity of concussions in the long run.

The statistical significance of recurrent concussion in relation to concussion severity has important implications for how concussion is viewed as an injury. Recovery from other injuries, such as broken bones or torn ligaments, can be easily measured, and thus, injured players are completely healthy when returning to play. However, because concussion severity significantly increases when the observed concussion is recurrent, perhaps players who suffer concussions return to play before they completely recover. With such critical long run health implications associated with concussions, recovery from a concussion cannot be taken lightly. In fact, with such a significant relationship between recurrent concussion and concussion severity, my research could suggest that complete recovery from concussion is not be entirely possible. To improve player safety in professional hockey, and eliminate the long run health concerns of concussions, research must be devoted into finding a more effective way to measure the process of recovery from concussion injuries.

The dataset compiled is the first large-scale dataset that combines video of concussions in the NHL, time loss associated with each concussion, and additional situational factors present at the time of each concussion event. The dataset is therefore quite valuable, and can be used in future studies about concussion severity in professional hockey. With new concussions observed in the NHL on a weekly basis, the dataset is constantly increasing in size. Further studies on concussions in the NHL using the dataset will therefore utilize even larger sample sizes.

Although my research study identified statistically significant relationships between situational factors present at the time of concussion, and concussion severity, room for further research exists. As previously mentioned, my research study in its present form omits velocity of contact when examining video of observed concussions in the NHL. The Head Injury Criterion, a model that computes the risk of head injury following certain impacts (usually car crashes), suggests that the risk of head injury increases as the velocity of an impact increases (Henn, 1998, p.1). The same reasoning can therefore be used in professional hockey. If the rapid acceleration and deceleration of the head following body contact is magnified due to larger hit velocities, both the risk of concussion and severe concussion should increase. My research is therefore not complete with this thesis. In a future study, I will collaborate with Atul Dar and Yigit Aydede to conduct survival analysis on observed concussions in the NHL. We will use SkillSpector software, in coalition with my video data, to measure the velocities present at each concussion incident. The newly modified dataset will then be used to determine whether a threshold velocity exists that causes concussion or severe concussion. Ultimately, our research study will allow us to predict the probability of recovery from an observed concussion based on different observable characteristics at the time of, and after, the observed concussion.

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