Protective equipment in youth ice hockey: are mouthguards and helmet age relevant to concussion risk?

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ABSTRACT

Objectives To compare the incidence rates and odds of concussion between youth ice hockey players based on mouthguard use and helmet age.

Materials and methods Within a 5-year longitudinal cohort (2013/2014 to 2017/2018) of male and female ice hockey players (ages 11–18; n=3330 players) in Alberta (Canada), we analysed the relationship of equipment and concussion in both a prospective cohort and nested case (concussion) control (acute musculoskeletal injury) approach. The prospective cohort included baseline assessments documenting reported mouthguard use (yes/sometimes, no use), helmet age (newer/<2 years old, older/≥2 years old) and important covariables (weight, level of play, position of play, concussion history, body checking policy), with weekly player participation throughout the season. The nested case–control component used injury reports to document equipment (mouthguard use, helmet age) and other information (eg, mechanism and type of injury) for the injury event. Multivariable mixed effects negative binomial regression (prospective cohort, incidence rate ratios (IRRs)) and multivariable mixed effects logistic regression (nested case–control, odds ratios (OR)) examined the association between equipment and concussion.

Results Players who reported wearing a mouthguard had a 28% lower concussion rate (IRR=0.72, 95% CI 0.56 to 0.93) and 57% lower odds of concussion (OR=0.43, 95% CI 0.27 to 0.70) compared with non-wearers. There were no associations in the concussion rate (IRR=0.94, 95% CI 0.75 to 1.15) and odds (OR=1.16, 95% CI 0.73 to 1.86) between newer and older helmets.

Conclusions Wearing a mouthguard was associated with a lower concussion rate and odds. Policy mandating use should be considered in youth ice hockey. More research is needed to identify other helmet characteristics (eg, quality, fit) that could lower concussion risk.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Mouthguard use for concussion prevention is controversial. Evidence suggesting that mouthguards decrease the likelihood of concussion is mixed. Few studies have prospectively examined mouthguard use and the rate of concussion and no study has examined helmet age and concussion in youth ice hockey.

WHAT THIS STUDY ADDS

⇒ We investigated both a prospective cohort and nested case (concussion) control (acute musculoskeletal injury) analytic evaluation of mouthguard use and helmet age with concussion in youth ice hockey. Wearing a mouthguard was associated with a 28% lower concussion rate and 57% lower concussion odds, with both off-the-shelf and dentist-fit types showing protection. Helmet age was not associated with the rate or odds of concussion.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Our findings support the introduction of policy that mandates the wearing of mouthguards across youth ice hockey leagues to promote player safety.

INTRODUCTION

Although a popular youth sport in Canada, the physicality and fast-paced gameplay in ice hockey is associated with a high rate of injury, including concussion.[1 2] Concussion is a traumatic brain injury caused by a blow to the head, face, neck or body.[3] Personal protective equipment for concussion prevention is largely understudied. However, some studies suggest that wearing a mouthguard and characteristics of the helmet (eg, fit, age) could be important modifiable risk factors for concussion.[4–6]

Modern mouthguards are composed of rubber-like materials (materials vary, but commonly made of polyvinyl–acetate–polyethylene copolymer) that cover the front of the maxilla (upper jaw) dentition and sits between the maxilla and mandible (lower jaw).[7] Mouthguard use is recommended for youth ice hockey players by Hockey Canada (Canada's national ice hockey organisation) to protect against dental injuries, resulting in some players wearing and others not wearing a mouthguard during play.[8] Furthermore, use of hockey helmets and full-face covering facemasks is mandatory for youth players in Canada with required certification by the Canadian Standards Association that does not include an expiry date.[8–10] It is up to the players (and parents) to monitor the helmet condition and determine when the helmet needs replacement. As a result, players may participate with helmets of varying ages.

In sport, mouthguards are mainly used to protect against dental and orofacial injuries.[11 12] However, a recent meta-analysis suggested a 19% reduction in the rate of concussion with mouthguard use.[4] Moreover, subsequent nested case (concussion) control (acute musculoskeletal injury) research in youth ice hockey players (ages 11–17, most players in elite levels of play) found players who wore a mouthguard to have 64% lower odds of concussion compared with players not wearing a mouthguard.[5] Nevertheless, assessment across all levels of play and concussion rates between mouthguard wearers and non-wearers requires further study. Helmet age and facemask type could be novel equipment-related modifiable risk factors for concussion prevention. Newer helmets may afford protection against concussion because of a lower likelihood of damage to the outer shell and padding due to less use; however, this has not been rigorously studied in youth ice hockey players.

The objective of this study, therefore, was to comprehensively assess whether mouthguard use (yes, no) and helmet age (newer/<2 years old, older/≥2 years old) are associated with concussion occurrence over a broad age range and across all divisions of youth ice hockey. A secondary question examined mouthguard types (off-the-shelf, dentist-fit) and facemask types (full-face wire cage, full-face shield/half cage-half shield) association with concussion.

METHODS

Design and participants

This study was part of a 5-year (2013–2018 seasons) longitudinal injury surveillance study in youth ice hockey players (ages 11–18). Participants included male and female players across all levels of play in the vicinities of the Canadian cities of Calgary and Edmonton. Mouthguard data from years 1–3 (2013–2016) of this study have been assessed previously when combined with a separate study of elite-only players (2011–2012, not included in the current investigation) for nested case (concussion) control (acute musculoskeletal injury) assessment.[5 13] The current study uniquely considered both a prospective cohort and nested case (concussion) control (acute musculoskeletal injury) approach with all 5 years of data collection across all levels of play. The sample size calculation for the 5-year longitudinal cohort was not based on the equipment variables, but rather for detecting differences in concussion rates by body checking policy.[14] Fortunately, the equipment variables were also captured supporting these analyses.

Procedures

Validated injury surveillance included baseline assessments, standardised injury reporting and recording of weekly participation in games and practices.[15–17] Baseline assessments included player demographics (eg, age, sex, weight), concussion history, player position, level of play, division of play and policy for body checking. Weight was either measured on a scale by the research team (69% of player-seasons) or if unavailable, self-reported by the participant on the baseline questionnaire (31% of player-seasons). Mouthguard use in both games and training/practices (never, sometimes/<75% of the time, always), mouthguard type (if use was indicated; dentist custom fit, off-the-shelf), helmet age (<2 years old, ≥2 years old) and facemask type (full wire cage, full clear shield, combination of half shield-half cage) were also collected at baseline. Game and training/practice participation were recorded on a weekly person-time exposure sheet by a team safety designate (eg, manager, coach, parent) along with the reason for any missed participation (hockey related injury, non-hockey related injury, sickness or other). An injury report form was initiated by the team designate for any hockey-related injuries, which was then validated and completed by a study athletic therapist. Any details for follow-up with a study sport medicine physician were also included. Injury data included injury date, type (eg, concussion), mechanism (eg, player to player contact), mouthguard use (and type), helmet age, facemask type and other information at the time of injury. If a concussion was suspected, players had access to a sport medicine physician at a university-affiliated sport medicine centre within 72 hours. A study athletic therapist reviewed all injury report forms and in the event of missing data, followed up by telephone with the participant. All data were stored into a secured electronic REDCap (Research Electronic Data Capture) database.[18]

Ice hockey injury was defined as either seeking medical attention (eg, physician, therapist, trainer), inability to complete the session (ie, game or training/practice) due to the injury, and/or missed participation in subsequent sessions due to the injury. Injuries were specified as a therapist-suspected or physician diagnosed concussion or musculoskeletal injury. Concussions were defined using the fourth international consensus statement on concussion in sport as being 'a complex pathophysiological process affecting the brain, induced by biomechanical forces'.[19] For the prospective cohort approach, the number of concussions sustained per player-season was the outcome. The nested case–control design compared concussion cases with all acute musculoskeletal injured controls sustained over the 5-year study with a single inciting event (ie, without chronic, gradual or overuse properties) and did not involve the neck, head or face (ie, injury locations between the shoulder and foot). Controls were selected from the same age groups, levels of play, and study years as cases.

Analysis

All analyses were completed using Stata V.16.1 with alpha (α) set at 5% (95% CIs).[20] For most variables, missing data ranged from 0% to 11.1% in the prospective cohort approach, and 0% to 14.7% (concussion—cases) and 15.7% (acute musculoskeletal—controls) in the nested case—control approach (tables 1 and 2). Helmet age and facemask type were the exception with the highest proportions of missing data for both the prospective cohort (11.2% and 11.7% missing) and nested case (concussion: 35.1% and 41.4% missing) and control (acute musculoskeletal injury: 23.6% and 43.8% missing) approaches (tables 1 and 2). Therefore, to maximise sample size, Multiple Imputation by Chained Equations (MICE, 20 imputations completed) models were used to estimate missing covariable information (previous concussion, weight and position of play) based on the outcome (either number of concussions or injury type—concussion, acute musculoskeletal injury), main exposures (mouthguard use and type, helmet age) and other covariables (player age, age group, height (cm), body checking policy and exposure hours). Multivariable mixed effects negative binomial regression (prospective cohort; gamma-distributed random effects and log link using mean–overdispersion for the overdispersion parameterisation), adjusted for cluster by team (random effect) and offset by player participation in games and practices (hours), was used to calculate incidence rates per 1000 playing hours and incidence rate ratios (IRR; with 95% CIs) for concussion between mouthguard use (and types), helmet age, and helmet facemask types. Multivariable mixed effects logistic regression analysis (Bernoulli distributed random effects), adjusted for cluster by team

Table 1 Participant demographic information for the prospective cohort and nested case–control analytic approaches

Variable	Prospective cohort	Nested case–control	
	Player-seasons (n=5356)	Player concussions (cases; n=490)	Player acute MSK injuries (controls; n=420)
Weight (kg), mean (SD)	55.1 (14.7)	57.1 (14.0)	60.7 (14.8)
Missing, n (%)	535 (10.0)	72 (14.7)	52 (12.4)
Level of play, n (%)			
Under 13	1535 (28.7)	84 (17.1)	48 (11.4)
Under 15	2255 (42.1)	235 (48.0)	176 (41.9)
Under 18	1566 (29.2)	171 (34.9)	196 (46.7)
Missing	0 (0)	0 (0)	0 (0)
Policy permitting body checking, n (%)			
No	2456 (45.9)	164 (33.5)	99 (23.6)
Yes	2719 (50.8)	310 (63.3)	318 (75.7)
Missing	181 (3.4)	16 (3.3)	3 (0.7)
Previous concussion, n (%)			
No	3020 (56.4)	202 (41.2)	192 (45.7)
Yes	2030 (37.9)	250 (51.0)	199 (47.4)
Missing	306 (5.7)	38 (7.8)	29 (6.9)
Position, n (%)			
Forward	2713 (50.7)	251 (51.2)	239 (56.9)
Defence	1604 (30.0)	163 (33.3)	123 (29.3)
Goalie	446 (8.3)	28 (5.7)	21 (5.0)
Missing	593 (11.1)	48 (9.8)	37 (8.8)
Sex, n (%)			
Male	4803 (89.7)	422 (86.1)	384 (91.4)
Female	530 (9.9)	68 (13.9)	34 (8.1)
Missing	23 (0.4)	0 (0)	2 (0.5)

Level of play included under 13 (formerly Pee Wee, ages 11–12), under 15 (formerly Bantam, ages 13–14) and under 18 (formerly Midget, ages 15–17).
MSK, musculoskeletal.

(random effect), was used to estimate odds ratios (ORs; with 95% CIs) for the relation between concussion and mouthguard use (and types), helmet age and helmet facemask type for the nested case–control approach. Incidence rates and IRRs provide a standardised comparison to experience the outcome (ie, concussion) when accounting for playing time at risk (ie, playing hours) between exposure groups (eg, mouthguard use, no use). The OR provides the odds of a case event (ie, concussion) in the exposed group relative to the unexposed group (eg, mouthguard use, no use). Clustering at the team level was used to account for

Table 2 Participant equipment information for the prospective cohort and nested case–control analytic approaches

Variable	Prospective cohort	Nested case–control	
	Player-seasons (n=5356)	Player concussions (cases; n=490)	Player acute MSK injuries (controls; n=420)
Mouthguard, n (%)			
No use	1064 (19.9)	185 (37.8)	120 (28.6)
Yes use	3871 (72.2)	251 (51.2)	234 (55.7)
Off-the-shelf type	2398 (62.0 of users)	101 (40.2 of users)	75 (32.1 of users)
Dentist-fit type	1376 (35.6 of users)	48 (19.1 of users)	55 (23.5 of users)
Missing type	97 (2.5 of users)	102 (40.6 of users)	104 (44.4 of users)
Missing use	421 (7.9)	54 (11.0)	66 (15.7)
Helmet age, n (%)			
<2 years	2710 (50.6)	193 (39.4)	163 (38.8)
≥2 years	2021 (37.7)	125 (25.5)	94 (22.4)
Missing	625 (11.7)	172 (35.1)	163 (38.8)
Facemask type, n (%)			
Full wire cage	4686 (87.5)	281 (57.3)	236 (56.2)
Full shield/shield-cage combo	68 (1.3)	6 (1.2)	0 (0)
Missing	602 (11.2)	203 (41.4)	184 (43.8)

Equipment (mouthguard use and type, helmet age, facemask type) for the prospective cohort is collected at baseline and at time of injury for the nested case–control approaches.
MSK, musculoskeletal.

potential non-independence of concussion outcomes between teammates (eg, coach instruction, aggressive team playing style, opponent rivalries). All models were adjusted for previously identified potential risk factors for concussion (weight, level of play, concussion history, body checking policy, position of play).[2 21 22] Assumptions for all variables were assessed prior to analysis. Effect measure modification was assessed separately for concussion history and mouthguard use, body checking policy and mouthguard use, helmet age and concussion history, and helmet age and body checking policy via the Wald test ($p<0.10$ is evidence of modification) in both approaches. We further examined interaction on the additive scale (combined effect of two exposures differs from the sum of their individual effects) using the relative excess risk due to interaction (RERI) for significant main protective equipment variables in the main model (ie, mouthguard use, helmet age, or both) separately with concussion history and body checking policy based on Knol *et al* adaptation of the RERI calculation for preventative factors.[23] There was no apriori sample size calculation completed for this study's objectives. However, with seven explanatory variables (1 continuous and 6 categorical variables, with 14 categories, totalling 10 degrees of freedom), to achieve a minimum of 10 events per variable, we would require at least 100 concussion and acute musculoskeletal injury events in the analyses.[24 25]

Equity, diversity and inclusion statement

The current study used an inclusive urban recruitment strategy for youth ice hockey players, regardless of sex, gender, ethnicity, or socioeconomic status in two prominent Canadian cities. This study's author team has representation from multiple backgrounds and perspectives, including differing career stages (student, junior researchers, senior researchers), sex, gender, membership with the LGBTQIA2S+community, disability, and ethnicity. As access and availability for healthcare may differ for participants, a strength of this study was to provide priority access for injury and concussion follow-up with a study-partnered sport medicine clinic. Unfortunately, our analyses could not adjust for sex differences due to few female participants playing in boys ice hockey leagues. However, we strongly advocate for future sport injury research to include female ice sports (eg, female ice hockey leagues, ringette).

RESULTS

There were 3330 players (1502 teams) recruited over the 5-year study (5356 player-seasons) with a total of 313 687.4 player-hours. Tables 1 and 2 display demographics and equipment information, respectively, for player-season observations (prospective cohort) and player injuries (nested case–control). Percent agreement (PA) for participants with non-missing baseline and injury report form data were above 80% for mouthguard use (PA=81.6%; 618/757), mouthguard type (PA=87.3%; 145/166), helmet age (PA=81.4%; 188/231), and facemask type (PA=98.5%; 265/269).

There were 490 player concussions (cases) over the 5-year study among 456 players (28 players suffered more than one concussion during the study) and 420 acute musculoskeletal injuries (controls, suffered by 358 players; 56 players sustained more than one acute musculoskeletal injury during the study). Approximately 90% of both concussion (n=435, 89.7%; missing: n=5) and acute musculoskeletal injuries (n=373, 89.4%; missing: n=3) occurred during gameplay.

There were 3871 (72.2%) player-seasons that reported wearing a mouthguard for the prospective cohort and 1064 (19.9%) player-seasons that did not (table 2). Of the wearers, 3330 (62.2%) player-seasons reported 'always' wearing a mouthguard in games and/or practices and 530 (9.9%) player-seasons reported 'sometimes' wearing a mouthguard in games or practices. Eleven player-seasons (0.2%) reported wearing a mouthguard more often in practices than in games (eg, 'always' for practices and 'sometimes' for games).

At baseline, 4686 player-seasons (98.6% non-missing data) reported wearing a full wire cage, 34 player-seasons (0.7%) wore a full shield and 34 player-seasons (0.7%) wore a half-cage half-shield (combined 68 player-seasons with shield component) (table 2). Five concussions (suffered by five players, out of a total of 68 player seasons and 3901.3 player-hours) occurred for those who reported wearing a facemask with a shield-component and 418 concussions (suffered by 362 players over the study period in 385 player-seasons, with a total of 4686 player-seasons and 276 496.2 player-hours) occurred for those who reported wearing a full wire cage facemask. The crude incidence rates (IR/1000 player hours) accounting for cluster by team was 1.29 (95% CI 0.19 to 2.99) for the shield-component facemasks and 1.56 (95% CI 1.38 to 1.75) for the full-wire cage facemasks. The resultant crude IRR (accounting for cluster by team, shield-component/full-wire cage) was 0.82 (95% CI 0.35 to 1.94). No players who sustained a musculoskeletal injury reported wearing a helmet facemask with a shield component, precluding calculation of ORs (table 2).

There was no evidence of effect measure modification between mouthguard use or helmet age with previous history of concussion or body checking policy with the rate and odds of concussion (p value >0.10, prospective cohort p value range: 0.14–0.64; nested case–control p value range: 0.23–0.90).

Results from the multivariable mixed effects negative binomial regression indicated a 28% lower rate of concussion when a mouthguard was worn (IRR=0.72, 95% CI 0.56 to 0.93) and no evidence of association between helmet age and concussion (IRR=0.94, 95% CI 0.75 to 1.15). Off-the-shelf mouthguard types were associated with a 33% lower concussion rate (IRR=0.67, 95% CI 0.51 to 0.88) and dentist-fit with a 24% lower concussion rate (not statistically significant, IRR=0.76, 95% CI 0.57 to 1.01) (table 3).

The multivariable mixed effects logistic regression model indicated a 57% lower odds of concussion for mouthguard wearers when compared with non-wearers (OR=0.43, 95% CI 0.27 to 0.70). Off-the-shelf type showed significant 42% lower concussion odds (OR=0.58, 95% CI 0.35 to 0.98) and dentist-fitted showed 69% lower concussion odds (OR=0.31, 95% CI 0.16 to 0.60) (table 3). The analyses also showed no evidence of association in the odds of concussion between helmet ages (table 3). Further comparison of RERI for mouthguard use (significant lower concussion rate and odds in main analyses) and important covariables (previous concussion, body checking policy) for the prospective cohort approach showed no significant additive interaction between mouthguard use and previous concussion (RERI=0.05, 95% CI −0.29 to 0.39) and mouthguard use and body checking policy (RERI=−0.06, 95% CI −0.47 to 0.35). There was also no significant additive interaction in the nested case–control approach for mouthguard use and previous concussion (RERI=0.16, 95% CI −0.34 to 0.66) and mouthguard use and body checking policy (RERI=0.11, 95% CI −0.86 to 1.07).

Supplemental results showed similar findings to the MICE models when data were considered in complete-case analyses. Mouthguard wearers had a significant 35% lower concussion rate and 56% lower concussion odds (both types protective) when compared with non-wearers, and no evidence of

Table 3 Main findings for mouthguard use, type and helmet age association with concussion

Variables	Prospective cohort analysis			Nested case–control analysis	
	Crude IR/1000 hours,* (95% CI)	MICE IRR,† (95% CI)	P value	MICE OR,‡ (95% CI)	P value
Mouthguard use					
No	2.15 (1.66 to 2.65)	1 (reference)		1 (reference)	
Yes	1.38 (1.18 to 1.59)	**0.72**§ **(0.56 to 0.93)**	0.014	**0.43**§ **(0.27 to 0.70)**	0.001
Off-the-shelf	1.27 (1.05 to 1.49)	**0.67**§ **(0.51 to 0.88)**	0.004	**0.58**§ **(0.35 to 0.98)**	0.042
Dentist-fitted	1.59 (1.22 to 1.96)	0.76 (0.57 to 1.01)	0.058	**0.31**§ **(0.16 to 0.60)**	0.001
Helmet age					
<2 years old	1.58 (1.32 to 1.84)	1 (reference)		1 (reference)	
≥2 years old	1.51 (1.25 to 1.77)	0.94 (0.75 to 1.15)	0.526	1.16 (0.73 to 1.86)	0.530
Weight (kg)	NA	1.00 (0.99 to 1.01)	0.564	0.99 (0.98 to 1.01)	0.322
Level of play					
Under 13	0.93 (0.70 to 1.15)	1 (reference)		1 (reference)	
Under 15	1.76 (1.43 to 2.08)	1.22 (0.83 to 1.81)	0.305	0.83 (0.39 to 1.76)	0.626
Under 18	1.97 (1.52 to 2.41)	1.35 (0.83 to 2.17)	0.223	0.56 (0.23 to 1.34)	0.191
Policy permitting body checking					
No	1.12 (0.89 to 1.34)	1 (reference)		1 (reference)	
Yes	1.99 (1.67 to 2.32)	**1.54**§ **(1.13 to 2.11)**	0.007	0.63 (0.35 to 1.13)	0.120
Previous concussion					
No	1.14 (0.94 to 1.33)	1 (reference)		1 (reference)	
Yes	2.25 (1.87 to 2.62)	**1.79**§ **(1.39 to 2.32)**	<0.001	**1.46**§ **(1.02 to 2.08)**	0.037
Position					
Forward	1.56 (1.32 to 1.80)	1 (reference)		1 (reference)	
Defence	1.67 (1.35 to 1.99)	1.10 (0.88 to 1.36)	0.387	1.32 (0.90 to 1.92)	0.153
Goalie	1.03 (0.56 to 1.50)	**0.58**§ **(0.38 to 0.90)**	0.015	1.07 (0.51 to 2.25)	0.854

*Crude incidence rates for concussion included 3953 player-seasons (360 concussions suffered by 307 players over the study period in 331 player-seasons) with 1157 team clusters (random effect) and 240 008.9 player-hours.
†MICE mixed effects multivariable negative binomial regression model for concussion included 4541 player-seasons (426 concussions suffered by 369 players) with 1230 team clusters (random effect) and 271 148.7 player-hours.
‡MICE mixed effects multivariable logistic regression model included 382 concussions (cases) suffered by 330 players over the study period in 352 player-seasons and 333 acute musculoskeletal injuries (controls) suffered by 281 players over the study period in 303 player-seasons, with 314 team clusters (random effect).
§Statistically significant finding based on apriori α (p<0.05). Level of play included under 13 (formerly Pee Wee, ages 11–12), under 15 (formerly Bantam, ages 13–14) and under 18 (formerly Midget, ages 15–17).
IR, incidence rate; IRR, incidence rate ratio; MICE, multiple imputation by chained equations; NA, not applicable.

association for helmet age (online supplemental table 1). Moreover, a second supplemental analysis showed no evidence of association between the rate of acute musculoskeletal injury (non-concussion outcome) by mouthguard use (IRR=0.95, 95% CI 0.70 to 1.29), mouthguard types (compared with non-wearers; $IRR_{off\text{-}the\text{-}shelf}$=0.97, 95% CI 0.69 to 1.35; $IRR_{dentist\text{-}fit}$=0.92, 95% CI 0.64 to 1.31) and helmet age (IRR=0.83, 95% CI 0.65 to 1.07) (online supplemental table 1).

DISCUSSION

This was the first study to our knowledge that considered both a prospective cohort and nested case–control analytic evaluation of personal protective equipment-related risk factors (ie, mouthguard, helmet) on the likelihood of sustaining a concussion in youth ice hockey players. Most concussions and acute musculoskeletal injuries (approximately 90%) occurred in game sessions, which is consistent with previous findings for injury and concussion rates in youth ice hockey and other collision-based sports (eg, tackle football, rugby).[26 27]

Mouthguard use (and types) compared with no use

There has been scepticism about the protective effects of wearing a mouthguard for protection against concussion.[28 29] Our findings showed consistent lower concussion rates and odds for mouthguard wearers compared with non-wearers. Moreover, we found both mouthguard types (when compared with non-wearers) to be associated with protection against concussion. Although not statistically significant, the estimate for the dentist-fit type in the prospective cohort analytic approach suggests a 24% lower concussion rate with CIs spanning from a clinically relevant 63% lower rate to a 1% higher rate. Supplemental analyses also showed consistent findings with complete-case analyses for mouthguard use association with a lower concussion rate and odds, and more interestingly, no association with mouthguard use or type and the rate of non-concussion acute musculoskeletal injury. These analyses confirm that there is an association between wearing a mouthguard and a lower likelihood of concussion in youth ice hockey with no apparent unintended injury consequences to mouthguard use. Our findings are consistent with a previous nested case–control study of youth ice hockey players (included data from years 1–3 of this current 5-year cohort study and an additional cohort of elite players not included in this study) that found a 64% lower odds of concussion for mouthguard wearers.[5] Moreover, examination at the Varsity ice hockey level also showed significant 57% lower odds of concussion for mouthguard wearers (compared with non-wearers). These findings are not consistent with other research in elite-level rugby and basketball that reported no differences in the rates of concussion between mouthguard wearers and non-wearers.[30–32] However, those studies included surveillance of a single (or few) teams within a single season of play and low occurrence of concussion injuries.[30–32] Although mainly examined in artificial skull models, hypotheses for mouthguard protection against concussion include lowering the forces transmitted to the brain via increased space at the temporomandibular joint, activation of neck and orofacial musculature, and shock absorption properties of the mouthguard.[11 33] However, further research for the proposed mechanisms within real-world participants during sport is required.

Helmet age and facemask type

Older helmets may have damage to the shell or worn padding compared with newer helmets, which may increase the risk of concussion.[9] However, we consistently found no difference in the concussion rate and concussion odds between newer (<2 years old) and older (≥2 years old) helmets. Our findings align with previous research in high school tackle football players in the USA that also found no statistically significant differences in the odds of concussion based on helmet age.[6] These findings may suggest wider and more specific helmet ages are needed for examination or perhaps that helmet age does not affect concussion risk.

Most players (>98%) in this study reported wearing a full-wire facemask type, and there was no evidence of association for the crude rates of concussion between cage and shield-component facemask types. Previous research found no difference in concussion occurrence between collegiate athletes wearing a full-face or half-face (eyes covered) shield coverage.[34] However, no previous study had examined different full-face covering facemask types and how they might relate to the risk of concussion in youth.

Other potential helmet-related modifiable risk factors for concussion prevention include helmet brand/design and helmet fit. Biomechanical analysis of different helmet brands showed different capabilities in protection from analysis of a concussive impact based on helmet width, structure, and padding material.[35 36] Moreover, in youth tackle football helmets with thicker padding on the zygomatic process and mandible were associated with lower concussion occurrence.[37] Finally, a previous study showed that youth ice hockey players with poor helmet fit were associated with a twofold greater odds of concussion when compared with healthy controls.[38] Therefore, future examination of helmet characteristics, including helmet fit, and concussion is warranted.

Limitations

A limitation of the current study includes assuming participants always wore a mouthguard if they reported 'sometimes' wearing a mouthguard. However, it is likely that use would be consistent among participants throughout the season and that use would be high in game sessions (where 90% of the concussions occurred). Indeed, we noted a high percentage agreement (>80%) between baseline documentation of mouthguards and mouthguard use reported at time of injury. Therefore, use of baseline reports for equipment in the prospective cohort design is reasonable to consider for the current sample. Ideally, future prospective cohort research would also document if a player wore a mouthguard when tracking individual player participation in game and practice sessions. A strength to the nested case–control approach is not relying on baseline reports but documenting equipment behaviours at the time of injury. The inclusion of non-diagnosed suspected concussions may lead to an overestimate of concussion injuries in this study. However, most concussions (84%, 410/490 concussions) were diagnosed by a physician, and all injuries (concussion and acute musculoskeletal) were verified by a study therapist using an objective injury definition, including medically identified and/or time loss from a session based on information surrounding mechanism, symptomology, suspected type and missed session time indicated on the injury report form and weekly exposure form. If injury information was unclear, a study therapist requested more detail from the participant through telephone follow-up.

There was a high proportion of missing helmet age information. We do not believe that having a newer (<2 years old) or older (≥2 years old) helmet age would affect injury follow-up; therefore, data are assumed to be missing at random and MICE analyses are deemed suitable for estimating missing data.

Although the current study met the rule of 10 events per variable recommendation for sample size, without an apriori power calculation, we may have been underpowered to assess interactions between mouthguard use and helmet age with a history of concussion and body checking policy. Future studies should examine the interactions between multiple risk factors and/or preventative factors influence on the risk of concussion. Ideally, we would have been able to account for clustering (ie, random effects) at both the team and individual player levels. However, the multilevel models did not converge when considering both levels of cluster; as such, we chose to adjust for team only as a random effect. This level was chosen as most players (83%, 568/681 injured players) over the 5 years did not sustain a repeat injury. Furthermore, adjusting for cluster by team would aid in controlling for potential non-independence in the likelihood for sustaining an injury between players on the same team due to unmeasured factors (eg, coach instruction, aggressive team playing style, opponent rivalries). We did not measure behaviour variables (eg, risk taking, belief in equipment) that may influence the likelihood of wearing a mouthguard and suffering a concussion. However, our supplemental analyses demonstrated no evidence of association between mouthguard use and the incidence rate of acute non-concussion musculoskeletal injury, which strengthens the notion of an association between wearing a mouthguard and concussion prevention. Finally, our analyses did not adjust for mechanism of injury between cases and controls; however, we restricted to only acute (single injury event) musculoskeletal injuries in the analyses to mimic the acute nature of concussion. Moreover, most acute musculoskeletal (74%, 310/420 injuries) and concussion (86%, 421/490 concussions) player injuries involved contact with another player recorded as the primary mechanism of injury. Therefore, we believe that it is unlikely that the mechanism of injury would significantly affect the results of this study.

CONCLUSION

Players who wore a mouthguard had a 28%–35% lower concussion rate and 56%–57% lower concussion odds compared with non-wearers. Both off-the-shelf and dentist-fitted mouthguard types showed protection compared with non-wearers. There was no significant difference found in the rate or odds of concussion by helmet age. Inclusion of both a prospective cohort and nested case–control study design for data analysis is unique to the current study and should be considered in future sport injury epidemiology literature. Future protective equipment research should examine types and characteristics across other collision-based sports (eg, tackle football, lacrosse, rugby) for prevention. The results from this study support a mandate of mouthguard use in youth ice hockey associations to promote concussion prevention and player safety.

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