Cyclist head and facial injury risk in relation to helmet fit: a case-control study

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Abstract

Introduction: We examined the effect of bicycle helmet fit and position on head and facial injuries.

Methods: Cases were helmeted cyclists with a head (n = 297) or facial (n = 289) injury. Controls were helmeted cyclists with other injuries, excluding the neck. Participants were interviewed in seven Alberta emergency departments or by telephone; injury data were collected from charts. Missing values were imputed using chained equations and custom prediction imputation models.

Results: Compared with excellent helmet fit, those with poor fit had increased odds of head injury (odds ratio [OR] = 3.38, 95% confidence interval [CI]: 1.06–10.74). Compared with a helmet that stayed centred, those whose helmet tilted back (OR = 2.90, 95% CI: 1.54–5.47), shifted (OR = 1.91, 95% CI: 1.01–3.63) or came off (OR = 6.72, 95% CI: 2.86–15.82) had higher odds of head injury. A helmet that tilted back (OR = 4.81, 95% CI: 2.74–8.46), shifted (OR = 1.83, 95% CI: 1.04–3.19) or came off (OR = 3.31, 95% CI: 1.24–8.85) also increased the odds of facial injury.

Conclusion: Our findings have implications for consumer and retail education programs.

Keywords: *head protective devices, bicycling, injuries*

Introduction

Helmets reduce the risk of head and facial injury in cycling crashes.[1] However, many cyclists do not wear their helmets correctly.[2] Bicycle helmet design and certification have changed during the past two decades.[3] While mandated use of bicycle helmets is increasing worldwide, a variety of types of legislation exist; some are restricted to youth, others apply to all ages.[4,5] Comparative studies in regions that have implemented helmet legislation have shown an overall decrease in reported traumatic brain injuries.[4,6,7] While this lends strength to arguments supporting helmet legislation, efforts to increase helmet use could fail to achieve the expected benefits to health outcomes if helmets are worn incorrectly.

Safety certification testing is typically based on drop tests, ensuring that the impact is delivered centred on the top of the helmet. In this setting, helmet effectiveness is based on ideal conditions, and a helmet's maximum protection is achieved when the helmet is correctly positioned. Proper fit is important in cases where the rider receives multiple hits to the head. Ensuring the helmet remains in place after the first blow protects against subsequent blows.[8]

Most of the literature on correct bicycle helmet use refers to the prevalence of correct use,[9] but reports vary largely due to the inconsistent criteria used to assess helmet fit. A 2010 study found that 20% of children aged under 13 years and 16.7% of 13- to 17-year-olds wore their helmets incorrectly.[10] The most frequently observed error was the helmet sitting too far back on the head. The upper rim of the helmet has been shown to protect the upper face from injury in a frontal collision,[1,11] and helmeted cyclists have a significantly lower risk of facial injury,[1,12] though it seems necessary that their helmets stay in place to do this. Only one study has investigated the relationship between bicycle helmet fit and the risk of head injury.[13] The authors found double the risk of head injury with a poorly fitting helmet compared with an excellently fitting helmet, triple the risk of head injury with a helmet that came off during the incident compared with one that stayed centred, and a 52% increase in risk of head injury in those with a helmet that tipped back compared with a helmet that stayed centred.[13] Though methodologically sound, this study used data captured nearly two decades ago, making it necessary to re-examine this issue with newer helmet designs. In addition, no studies have reported how proper helmet use and correct fit affect facial injuries among cyclists.

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The purpose of our study was to determine the relation between the risk of head or facial injury and self-reported bicycle helmet fit and position.

Methods

Data collection

Injured cyclists were recruited from seven emergency departments (EDs) in Calgary (Alberta Children's Hospital, Foothills Medical Centre, Rockyview General Hospital, Peter Lougheed Centre) and Edmonton (Stollery Children's Hospital, University of Alberta Hospital, Northeast Community Health Centre), Alberta, over three years (May 2008 to October 2010). We identified the cyclists by scanning the Regional Emergency Department Information System and reviewing ED charts daily, with the co-operation of the ED staff. Eligible injured cyclists (or parents of those aged less than 14 years) were approached and asked to participate by research staff or, in some cases, the ED physician or nurse.

After giving consent, patients were interviewed in the ED or, if they did not wish to complete the interview immediately, by telephone. If an eligible patient was missed in the ED, they were mailed a study information package including a consent form and were contacted by telephone and asked to participate. If a patient was admitted to the hospital after their ED visit, the research staff made arrangements to inform the patient about the study and interview them in hospital if they were willing. If the patient was too young to answer the questions, research staff interviewed the patient's parent or guardian. If the parent did not know the details of the event or could not respond to a question, responses were filled out as ''don't know'' or ''missing,'' as appropriate. For telephone interviews, we requested the participation of the child; however, if the parent did not allow the child to respond on their own, responses from the parent were accepted instead.

We collected injury information from the patient's medical chart. Excluded from the study were injured cyclists who did not speak English, those missed in the ED who did not have a telephone or who could not be reached after a maximum of six call attempts, and those who were injured while riding indoors or while using a stationary bicycle. We also did not include cyclists who received a neck injury as the relationship between helmet use and neck injury risk is less clear or well-accepted.[7]

From within this arm of the study focusing on helmet fit, we identified two separate case groups. The first consisted of helmeted cyclists who had received a head injury, regardless of the severity of any other injuries. A head injury was defined as any injury to the scalp, skull or brain and did not include injuries to the cervical vertebrae or spinal cord, injuries to the point where the skull meets the spine or injuries to the neck regions or the face. The boundaries of the skull were defined as an imaginary line from normal eyebrow position laterally to the normal hairline, descending posterior to and not including the ears, and to and around the base of the occipital bone.

Since there is some evidence that bicycle helmets prevent facial injuries,[1] our second case group consisted of helmeted cyclists who had received any injury to the face, regardless of the severity of any other injuries. A facial injury was defined as any injury below the normal hairline, anterior to and including the ears, and superior to and including the mandible. Cyclists with both head and facial injuries were included in both case groups. Controls, obtained from the same EDs as the cases, were helmeted cyclists who had received injuries below the neck and had no head, brain or face injuries.

We interviewed bicyclists in the ED using a structured questionnaire (available on request) based on previous work[14,15] that was pilot tested with a convenience sample of respondents. Survey information was captured on the cyclist and the circumstances of the crash. For this analysis, we focused on information that related to helmet use and helmet fit. The two main variables of interest, helmet fit and helmet position/movement during the crash, were self-reported using fixed-response choices. For helmet fit, the response choices were (1) excellent, (2) good, (3) fair and (4) poor. Helmet position response choices were (1) stayed centred, (2) tilted back, (3) shifted to the side and (4) came off. For both variables participants could also respond ''don't know'' or ''refuse to answer,'' both of which were treated as missing values for the primary analysis.

Follow-up interviews were conducted with a subsample of participants to measure the reliability of the initial interview. The same questionnaire was used and the initial respondent was asked to complete the follow-up interview (e.g. the parent if they responded initially). The results of the two time-separated interviews were compared using kappa (κ) statistics[16] with 95% confidence intervals (CIs). The follow-up interviews were conducted at least two weeks after the initial interview with those patients who had agreed to be contacted for follow-up during the initial interview.

The study was approved by the Conjoint Health Research Ethics Board at the University of Calgary and the Health Research Ethics Board at the University of Alberta.

Data analysis

We calculated crude odds ratios (ORs, with 95% CIs) for the association between helmet fit and head or facial injury. We also examined the relation between helmet position during the crash and head or facial injury. Multiple logistic regression analyses were conducted to adjust for potential confounders (i.e. variables potentially related to helmet fit/position and independent risk factors for head or facial injury) including age, sex, body mass index (BMI), cycling frequency, presence of a cycling companion and cyclist self-reported estimated speed. Age was categorized as less than 13 years, 13 to 17 years, 18 to 39 years or 40 years and older. BMI categories were based on the World Health Organization classifications for underweight (< 18.50 kg/m^2), normal weight (18.50–24.99 kg/m^2), overweight (25.00–29.99 kg/m^2) and obese (≥ 30 kg/m^2).[17] Cycling frequency was classified as at least once per week, at least once per month or at least once per year.[18] Cyclists were grouped as cycling alone, with children, with adults or with others (e.g. camp leaders). Cyclist speed was dichotomized into less than 25 km/h and greater than or equal to 25 km/h. A forward selection modelling strategy was used where each co-variate was added to the model containing outcome (head or facial injury) and exposure (helmet fit or helmet position) individually. Separate models were developed for helmet fit and helmet position to avoid potential collinearity of the two variables. If a co-variate produced a change in helmet fit or position estimates of greater than or equal to 10%, it was retained in the model. This process was repeated until no more changes were observed or until the number of variables in the model reached 10% of the number of cases.[19]

Multiple imputation analysis

We imputed missing values for exposure variables and potential confounders using chained equations and custom prediction imputation models.[20] In the imputation model, variables were imputed in order of least missing to most missing using predictive mean matching for continuous variables and multinomial logistic or ordered logistic regression for categorical variables as appropriate. Non-missing predictors were also included. Logistic regression models including all co-variates (age, sex, BMI, cyclist speed, cycling frequency and cycling companions) were used to calculate OR estimates and 95% CIs from the imputed data. All data analyses were conducted using STATA version 11.0 (StataCorp LP, College Station, TX, US).

Results

Characteristics of the study sample

In total, 4960 injured cyclists were screened for eligibility and 3111 (63%) agreed to participate and were enrolled into the study. Of these, 2336 (75%) were wearing a helmet at the time of the crash. For this analysis, there were 297 cyclists with a head injury, 289 facial injury cases and 1694 controls. There were 64 participants who had both head and facial injuries; these were included in both case groups.

Table 1 shows the characteristics of the groups of cyclists with head and facial injuries. Compared with controls, the cyclists with head injuries tended to be biking faster and were more likely to be biking alone, while those with facial injuries were younger, had a lower BMI, were cycling alone or with adults and rarely used a full-face helmet.

Helmet fit and position and risk of head injury

Based on the crude estimates, poor helmet fit significantly increased the odds of head injury relative to the excellent fit category (OR = 3.26, 95% CI: 1.08–9.83) (Table 2). If the helmet tilted back (OR = 2.76, 95% CI: 1.47–5.18), shifted to the side (OR = 1.87, 95% CI: 1.03–3.42), or came off (OR = 6.77, 95% CI: 3.08–14.86), the odds of head injury increased significantly relative to the ''stayed centred'' group.

The adjusted ORs for good, fair and poor helmet fit were 0.96 (95% CI: 0.69–1.36), 1.93 (95% CI: 1.04–3.57), and 3.23 (95% CI: 0.78–13.41), respectively, compared with excellent helmet fit. Cyclists who reported a fair helmet fit had nearly twice the odds of incurring a head injury compared with those who reported an excellent helmet fit. After conducting the imputation, only those who reported poor helmet fit (OR = 3.38, 95% CI: 1.06–10.74) had significantly increased odds of head injury relative to those with excellent helmet fit.

After adjustment for co-variates, cyclists with a helmet that came off during the crash had a 7-fold increase in the odds of head injury compared with those whose helmet stayed centred (OR = 7.13, 95% CI: 2.94–17.29). Those with a helmet that tilted back had more than a three-fold increase in the odds of a head injury (OR = 3.54, 95% CI: 1.70–7.40). The adjusted estimates based on the imputed data were similar; the OR estimate for a helmet that tilted back was 2.90 (95% CI: 1.54–5.47) and the estimate for a helmet that came off was 6.72 (95% CI: 2.86–15.82). The result for a helmet that shifted to the side was also significant after imputation (OR = 1.91, 95% CI: 1.01–3.62).

Helmet fit and position and risk of facial injury

Crude estimates showed increased odds of facial injury with a helmet that tilted back (OR = 4.19, 95% CI: 2.46–7.15), shifted to the side (OR = 1.98, 95% CI: 1.11–3.50) or came off (OR = 3.12, 95% CI: 1.19–8.22) (Table 3). However, when adjusted for BMI, cycling frequency and cycling speed, only those helmets that tilted back were associated with an increase in the odds of facial injury (OR = 4.49, 95% CI: 2.30–8.77). Poor fit was indicative of a harmful effect but was not statistically significant (OR = 3.10, 95% CI: 0.76–12.69).

Compared with the adjusted estimates from the original data, the imputed ORs for facial injury risk tended to be further from 1.00. The odds of facial injury increased significantly if the helmet tilted back (OR = 4.81, 95% CI: 2.74–8.46), shifted to the side (OR = 1.83, 95% CI: 1.04–3.19) or came off (OR = 3.31, 95% CI: 1.24–8.85).

Data quality and reliability

For helmet fit, overall observed agreement was 87.5% and expected agreement was 81.0% (Table 4). Weighted kappa was calculated since the responses were ordered, and kappa was 0.34 (95% CI: 0.16–0.64), which represents fair agreement.[14] For head and face injury cases (n = 24), observed agreement was 91.7% and expected agreement was 79.8%, resulting in a kappa of 0.59 (95% CI: 0.28–1.00), representing moderate agreement. For controls, kappa was 0.22 (95% CI: 0.00–0.44).

An un-weighted kappa score was calculated for helmet position. For head and face injury cases, observed agreement was 62.5%, expected agreement was 49.3% and kappa was 0.26 (95% CI: 0.00–0.54) or fair agreement. For controls, observed agreement was 90.6%, expected was 85.6%, and kappa was 0.35 (95% CI: 0.19–0.71), fair agreement.

Discussion

This study provides updated evidence on the relationship between correct bicycle

TABLE 1
Cyclist and crash characteristics by case-control status for cyclists injured in Calgary and Edmonton, Alberta

	Controls (n = 1694)		Head injury (n = 297)		Chi² (χ^2) *p* value	Facial injury (n = 289)		Chi² (χ^2) *p* value
	n	(%)	n	(%)		n	(%)	
Sex					.70			.88
Female	450	(26.6)	76	(25.6)		78	(27.0)	
Male	1244	(73.4)	221	(74.4)		211	(73.0)	
Age, years					.14			≤ .001
< 13	695	(41.0)	101	(34.0)		154	(53.3)	
13–17	394	(23.3)	77	(25.9)		41	(14.2)	
18–39	308	(18.2)	56	(18.9)		53	(8.0)	
≥ 40	297	(17.5)	63	(21.2)		41	(14.2)	
BMI, kg/m²					.34			.03
< 18.50 (underweight)	407	(24.0)	69	(23.2)		89	(30.8)	
18.50–24.99 (normal)	783	(46.2)	154	(51.9)		125	(43.3)	
25.00–29.99 (overweight)	279	(16.5)	40	(13.5)		41	(14.2)	
> 30.00 (obese)	56	(3.3)	6	(2.0)		4	(1.4)	
Unknown[a]	169	(10.0)	28	(9.4)		30	(10.4)	
Cyclist speed, km/h					< .001			.20
< 25	1240	(73.2)	183	(61.6)		199	(68.9)	
≥ 25	181	(10.7)	42	(14.1)		33	(11.4)	
Unknown[a]	273	(16.1)	72	(24.2)		57	(19.7)	
Cycling frequency					.14			.89
At least once per week	1476	(87.1)	257	(86.5)		253	(87.5)	
At least once per month	102	(6.0)	13	(4.4)		12	(4.2)	
At least once per year	57	(3.4)	10	(3.4)		12	(4.2)	
Unknown[a]	59	(3.5)	17	(5.7)		12	(4.2)	
Cycling with others					< .001			.02
Cycling alone	545	(32.2)	127	(42.8)		103	(35.6)	
With adults	643	(38.0)	95	(32.0)		124	(42.9)	
With children only	493	(29.1)	74	(24.9)		59	(20.4)	
With someone else[b]	12	(0.7)	0	(0.0)		3	(1.0)	
Unknown[a]	1	(0.1)	1	(0.3)		0	(0.0)	
Helmet type					.23			≤ .001
Full-face helmet	258	(15.2)	34	(11.5)		17	(5.9)	
No face guard	1405	(82.9)	257	(86.5)		269	(93.1)	
Don't know about face guard[c]	26	(1.5)	4	(1.4)		2	(0.7)	
Unknown[a]	5	(0.3)	2	(0.7)		1	(0.4)	

Abbreviation: BMI, body mass index.

[a] The ''unknown'' category includes the responses ''don't know,'' ''refused to answer'' and where the data were missing. This category was not included in the tests of significance.

[b] Includes responses that were not possible to categorize as ''adult'' or ''child'' companions (e.g. cycling with an instructor or a baby-sitter).

[c] The question about type of helmet was added in year two (2009) of data collection and so information on the use of a face guard was not available for participant interviews in year one (2008).

helmet fit and risk of head or facial injuries. While the overall protective effect of bicycle helmets has been well documented, specific information on helmet fit and position increases our understanding of their impact and provides evidence that can be used by cyclists, helmet manufacturers and those promoting injury prevention.

Rivara et al.[13] reported an increase in head injury risk as a result of cyclists' helmets shifting back or coming off. Our results were approximately twice as high as those previously reported. We also found a relationship between head injury and a helmet that shifted to the side, an observation that had not been previously

TABLE 2
Odds ratio estimates for the relationship between helmet fit and head injury among cyclists injured in Calgary and Edmonton, Alberta

	Controls (n = 1694)		Cases (n = 297)		Crude OR (95% CI)		Adjusted OR (95% CI)		Imputed adjusted OR[a] (95% CI)	
	n	(%)	n	(%)						
Helmet fit[b]										
Excellent	1014	(59.9)	173	(58.1)	1.00	(reference)	1.00	(reference)	1.00	(reference)
Good	579	(34.2)	92	(30.9)	0.93	(0.71–1.22)	0.96	(0.69–1.36)[c]	0.97	(0.73–1.29)
Fair	81	(4.8)	22	(7.4)	1.59	(0.97–2.62)	1.93	(1.04–3.57)[c]	1.60	(0.96–2.66)
Poor	9	(0.5)	5	(1.7)	3.26	(1.08–9.83)	3.23	(0.78–13.41)[c]	3.38	(1.06–10.74)
What happened to your helmet?[d]										
Stayed centred	1421	(83.9)	180	(60.4)	1.00	(reference)	1.00	(reference)	1.00	(reference)
Tilted back	40	(2.4)	14	(4.7)	2.76	(1.47–5.18)	3.54	(1.70–7.40)[e]	2.90	(1.54–5.47)
Shifted to side	59	(3.5)	14	(4.7)	1.87	(1.03–3.42)	1.84	(0.90–3.77)[e]	1.91	(1.01–3.63)
Came off	14	(0.8)	12	(4.0)	6.77	(3.08–14.86)	7.13	(2.94–17.29)[e]	6.72	(2.86–15.82)
Tilted forward	10	(0.6)	2	(0.7)	1.58	(0.34–7.26)	1.39	(0.17–11.61)[e]	1.52	(0.32–7.19)

Abbreviations: BMI, body mass index; CI, confidence interval; OR, odds ratio.

Note: Missing values in original data: age (n = 7), height (n = 159), weight (n = 82), helmet fit (n = 16), cyclist speed (n = 345), helmet position (n = 225), cycling frequency (n = 76) and cycling companion (n = 2).

[a] Estimates adjusted for cycling frequency, presence of cycling companion, speed, BMI, sex and age.

[b] Adjusted analysis includes 198 cases and 1244 controls before imputation.

[c] Estimates adjusted for cycling frequency, speed, BMI and age.

[d] Adjusted analysis includes 166 cases and 1178 controls before imputation.

[e] Estimates adjusted for speed, cycling companion and BMI.

TABLE 3
Odds ratio estimates for the relationship between helmet fit and facial injury among cyclists injured in Calgary and Edmonton, Alberta

	Controls (n = 1694)		Cases (n = 289)		Crude OR (95% CI)		Adjusted OR[a] (95% CI)		Imputed adjusted OR[b] (95% CI)	
	n	(%)	n	(%)						
Helmet fit[c]										
Excellent	1014	(59.9)	165	(57.1)	1.00	(reference)	1.00	(reference)	1.00	(reference)
Good	579	(34.2)	106	(36.7)	1.13	(0.86–1.47)	0.95	(0.69–1.32)	1.11	(0.85–1.46)
Fair	81	(4.8)	14	(4.8)	1.06	(0.59–1.92)	0.91	(0.42–1.98)	1.05	(0.58–1.93)
Poor	9	(0.5)	3	(1.0)	2.05	(0.55–7.65)	3.10	(0.76–12.69)	2.08	(0.54–8.02)
What happened to your helmet?[d]										
Stayed centred	1421	(83.9)	195	(67.5)	1.00	(reference)	1.00	(reference)	1.00	(reference)
Tilted back	40	(2.4)	23	(8.0)	4.19	(2.46–7.15)	4.49	(2.30–8.77)	4.81	(2.74–8.46)
Shifted to side	59	(3.5)	16	(5.5)	1.98	(1.11–3.50)	1.51	(0.72–3.17)	1.83	(1.04–3.19)
Came off	14	(0.8)	6	(2.1)	3.12	(1.19–8.22)	3.08	(0.95–9.93)	3.31	(1.24–8.85)
Tilted forward	10	(0.6)	2	(0.7)	1.46	(0.32–6.70)	2.02	(0.41–9.99)	1.54	(0.35–6.85)

Abbreviations: BMI, body mass index; CI, confidence interval; OR, odds ratio.

Note: Missing values in original data: age (n = 6), height (n = 163), weight (n = 71), helmet fit (n = 12), cyclist speed (n = 330), helmet position (n = 194), cycling frequency (n = 71) and cycling companion (n = 1).

[a] Estimates adjusted for BMI, cycling frequency and cycling speed.

[b] Estimates adjusted for cycling frequency, cycling companion, speed, BMI, sex and age.

[c] Adjusted analysis includes 198 cases and 1244 controls before imputation.

[d] Adjusted analysis includes 170 cases and 1318 controls before imputation.

TABLE 4
Agreement and kappa for helmet fit and position by cases and controls for cyclists injured in Calgary and Edmonton, Alberta

	Observed agreement, %	Expected agreement, %	κ	95% CI
Cases (n = 24)				
Helmet fit	91.7	79.8	0.59	(0.28–1.00)
Helmet position	62.5	49.3	0.26	(0.00–0.54)
Controls (n = 53)				
Helmet fit	85.5	81.6	0.22	(0.00–0.44)
Helmet position	90.6	85.6	0.35	(0.19–0.71)
Overall (n = 77)				
Helmet fit	87.5	81.0	0.34	(0.16–0.64)
Helmet position	81.8	72.0	0.35	(0.20–0.74)

Abbreviations: CI, confidence interval; κ, kappa.

reported. We did not find that self-reported helmet fit influenced the odds of a facial injury, but a helmet that came off during a crash increased the odds of facial injury 3-fold and a helmet that tilted back increased the odds of facial injury almost 5-fold.

Foss and Beirness[21] reported that incorrect helmet use is more prevalent in 1- to 5-year-olds and 6- to 15-year-olds compared with older cyclists and that those aged 6 to 15 years have a higher risk of head injury.[21] Their definition of incorrect helmet use included an unfastened chin strap or a helmet that was tipped back.[21] We also found that the youngest age group (< 13 years old) suffered a high proportion of head and facial injuries compared with older age groups, which may be related to having a helmet that tilted back in the crash.

Another Canadian study found that 4.3% of helmet users wore their helmet incorrectly, either tipped back, with the chin strap unfastened or with a baseball cap worn underneath.[22] A 2010 observational study in Alberta[10] showed that 16.6% of cyclists—and 21% of children aged under 13 years—used a helmet incorrectly. In our study, approximately 9% of those with head injuries and 6% of those with facial injuries reported fair or poor helmet fit compared with 5.3% of controls. These are likely underestimates, as Lee et al.[9] reported that the prevalence of correct helmet use varied from 46% to 100% among recent studies, noting inconsistencies in the definition of correct use.

Our findings on the importance of helmet fit provide a better understanding of the potential protective effect of bicycle helmets. Previous studies that documented that helmet use (vs. non-use) reduces the risk of a head or brain injury[1] may in fact underestimate the protective effect of helmets given that it is likely that a number of the participants in these studies were wearing a poorly fitting helmet or using the helmet incorrectly (e.g. strap not fastened). If so, this has implications for the promotion of helmet use, which should include a focus on how to wear helmets correctly in order to achieve the maximum protective benefit.

Limitations

If cyclists who did not participate differed in their helmet use compared with the study sample, there is potential for selection bias. Unfortunately, in addition to lack of information on helmet use for these patients, the nature of the data collection process made it impossible for us to determine whether or not those we could not reach or who refused to participate would have been cases or controls. If those who refused were more likely to wear their helmet incorrectly and this resulted in more severe injuries involving the head or face, then we would have underestimated the protective effect of a helmet that fit correctly or stayed centred. Helmet fit was self-reported, and therefore may be prone to misclassification if cyclists were more likely to indicate that the helmet fit better than it actually did. It may be that those without a head injury would over-report excellent helmet fit and those with a head injury under-report excellent fit. If so, this would have resulted in an inflated estimate of the effect of poor helmet fit. Lee et al.[9] found that self-perceived helmet fit was often over-estimated compared with expert evaluation, meaning that the helmet fit risk estimates in our study could be biased. We had high observed agreement between the initial and follow-up reported helmet fit for cases (91.7%) and controls (85.5%); though kappa values were lower for controls and could potentially reflect misclassification bias of the odds ratios toward or away from the null. The poorer reliability estimates for helmet position were similar for cases and controls and may indicate misclassification that would push the odds ratios to the null.

We included several potential confounders that have been shown to relate to bicycling injury. These included cycling frequency, presence of a companion, speed, BMI, sex and age. In their study, Rivara et al.[13] presented unadjusted results after determining that crash severity did not influence the effect estimates for the relationship between head injury risk and helmet fit or position. Therefore, it is unlikely that other factors related to both bicycling head and facial injury and helmet fit could account for the effects we have identified.

Conclusion

Helmet fit and position during a crash can significantly affect the risk of head and face injuries. Correct helmet use may be increased as a result of educational programs informing cyclists that wearing a helmet is not enough to provide full protection without considering proper fit. Manufacturers should continue to try to design easy-to-use helmets in many different shapes and sizes that stay in place to best protect the cyclist. Retail employees selling helmets must be trained in the principles of correct helmet use to convey this important information to consumers.

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