Helmet use and injuries in children's bicycle crashes in the Gothenburg region

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ABSTRACT

Aim: To investigate the use and protective effect of helmets in children injured in bicycle crashes and changes in injury patterns during a period of increased helmet use.

Method: Injuries in 4246 children below 16 years of age, who attended an A&E ward after a bicycle crash in the Gothenburg region during 1993-2006, were analysed. The injury severity was classified according to the Abbreviated Injury Scale. The occurrence of skull/brain injuries and facial injuries was analysed for 3711 children with respect to injury severity, helmet use and demographic and crash-related factors. Changes in injury patterns during the period were analysed for 4246 children with no regard to helmet use. The ratio of the number of subjects with head injuries to the number of subjects with extremity injuries was used to estimate the protective effect of wearing a helmet at population level.

Results: Helmets were used by 40 % of the injured children at the beginning of the period and by 80 % at the end; much less frequently by teenagers, especially girls. The odds of sustaining serious or more severe skull/brain injuries and moderate or more severe facial injuries with a helmet were about one fourth of those without a helmet. The proportion of children with skull/brain injuries did not change significantly during the period. The proportion of children with facial injuries decreased, and the proportion with injuries to the upper extremities increased. The ratio between the number of children with head injuries and the number with extremity injuries decreased.

Conclusions: Bicycle helmets have an obvious protective effect against head injuries in children, regardless of the crash circumstances. Teenagers must be informed about the high risk of skull/brain injuries in bicycle crashes without a helmet. Attention should be paid to the increasing occurrence of injuries to the upper extremities.

Key words: bicycle accident, children, helmet, injury, head, extremity.

1 INTRODUCTION

There are strong environmental and health-related reasons why cycling should be encouraged. Bicycle transport creates a minimum of pollution and provides exercise, fitness, health, joy, and economy. Hence, cycling has increased in many countries, including Sweden, in recent years, as has the number of bicycle accidents.

In Sweden, the risk of being killed in road traffic as a cyclist is about six times that of car occupants and, since 2008, cyclists make up the largest group of severely injured road users (hospitalised at least 24 hours) [1]. The annual number of fatally injured cyclists below 20 years of age was low (less than seven or 0.14/100 000) during 1997-2012 [2]. An annual average of 3 578 (185/100 000) children below 18 years of age were severely injured in road traffic crashes during 2005-2009, with cyclists being the largest group (64/100 000). An additional 10 300 (537/100 000) children, injured as cyclists, attended accident and emergency (A&E) departments (mean value per year) during 2007-2009 [3].

Cyclists most commonly receive injuries to the head and upper extremities [3]. Although the incidence rate of traumatic brain injuries is low in Sweden, brain injury is a significant cause of permanent disability in children. Traumatic brain injuries account for two thirds of all post-neonatal mortality [4]. Negative effects of traumatic brain injuries may influence school results, leisure activities and thoughts about the future life situation [5]. Cyclists comprised the majority of trauma cases admitted to a paediatric intensive care unit in Gothenburg in 1990-2000, and the most commonly injured body region was the head [6].

Injury prevention programmes have resulted in a steady increase in helmet use among school-age children, from about 5 % in 1988 to about 40 % in 2004 [7]. Helmet legislation was implemented in Sweden in January 2005, for children below 16 years of age. Despite this, only about 60 % of the children used a helmet in 2012, when cycling to and from school, and only about 40 % of 13-15-year-olds [7].

Although many studies have shown that bicycle helmet use reduces the risk of head [8-18], face [8,9,12,15] and fatal injuries [9,14], this conclusion has also been challenged [19-22]. Arguments such as 'the brain can be injured without impact to the head' [21,22], 'helmets may not provide significant protection in collisions with other vehicles' [19], 'car drivers take less care when manoeuvering around cyclists who wear a helmet', and 'helmeted cyclists take more risks than non-helmeted cyclists', may explain why helmets fail to reduce effectively the overall level of head injuries and death [19,20]. Some previous studies on risk-taking behaviour have produced contradictory results [13,23]. Furthermore, the compulsory usage of bicycle helmets has been said to be detrimental to public health, as cycling decreased sharply after the legislation was implemented in Australia, New Zeeland, and Canada [24,25].

Some authors have investigated the effect of helmets with regard to injuries to other body regions than the head [12,16,26]. In these studies, only 8-16 % of the subjects used a helmet, including cyclists attending A&E departments only. As cyclists with helmets are less likely to receive injuries to the head, and therefore do not seek medical care as often as cyclists without a helmet, the results may not be representative of all injured cyclists. Other authors have estimated the protective effect of helmets against head injuries at population level by relating the number of head injuries to the number of limb injuries in cyclists attending A&E departments [28,29].

Accident data should be used for intervention and prevention. Health care professionals can highlight risks associated with cycling and such data play an important role for society in making cycling a safe activity. As bicycle helmet use has increased among children in Sweden during the last decades, the injury patterns in bicycle crashes may have changed. The purpose of this study was to investigate the use of helmets by gender and age in children injured as cyclists and the protective effect of helmets against head injuries, with respect to demographic and crash-related factors, and to examine changes in injury patterns during a period of increased helmet use.

The study has been approved by The Ethical Review Board, University of Gothenburg, Sweden.

2 METHODS AND SUBJECTS

This is a retrospective observation study of children who sought care at an A&E department in Gothenburg due to injuries after cycling crashes during 1993-2006.

2.1 Data collection

Recording of traffic accident casualties was introduced at the A&E departments in Gothenburg at the end of the 1970s. The date, time and site of the crash, type of road user, counterpart, type of crash, type of environment (distinguishing type of road, crossing or not, bicycle lane, etc., in road traffic on the one hand, and private areas and other off-road environments, on the other), the purpose of the transport, the mode of transportation to the hospital (ambulance or not), use of protective equipment, and injuries, have been recorded in a structured way in the Traffic Injury Register, Department of Orthopaedics at Sahlgrenska University Hospital, Gothenburg. The procedure is used in the national information system for recording of traffic injuries in Sweden (STRADA) [25]. Two persons with long experience of the procedure recorded the accident circumstances and the injuries in the present study, which includes all casualties recorded in 1993-2006.

Medical records were used to classify the diagnoses and the severity of the injuries. The diagnoses were specified according to the Swedish version of the WHO International Classification of Diseases (ICD9 and ICD10) [31,32]. The severity of the injuries was classified according to the Abbreviated Injury Scale (AIS-90) [33]. The localisation of the injuries was assigned to the following body regions: skull/brain, face, neck (including the cervical spine), upper extremity (including the shoulder), upper trunk (including the thoracic spine), lower trunk (including the lumbar spine and external genitals), and lower extremity (including the pelvis). The AIS code includes a digit between 1 and 6, the AIS grade for each well-described injury, coarsely corresponding to the threat to life of the injury, defined on an ordinal scale as: 1=minor; 2=moderate; 3=serious; 4=severe; 5=critical; 6=maximum. The grades 4-6 are considered life-threatening injuries. The maximum AIS (MAIS) is a descriptor of the overall injury severity. The MAIS can also be defined for each of the specified body regions.

In this study, skull/brain injuries include superficial injuries (abrasions or contusions) and wounds to the scalp, fractures of the vault or skull base, and injuries to or bleeding in the brain or brain stem. Facial injuries include superficial injuries and wounds, fractures of the facial skeleton, and injuries to the eye and external ear. Injuries to the trunk and extremities include superficial injuries and wounds, distortions/dislocations and fractures, as well as injuries to internal organs, great vessels and nerves in the thorax and abdomen, and the spinal cord.

2.2 Statistical methods

Helmet use was analysed with univariate models in order to identify possible connections with demographic and crash-related factors.

The odds of a skull/brain and facial injury of a specified severity with and without a helmet were derived from contingency tables. The MAIS score for the body region was used for discrimination purposes, and cases without an injury to the body region in question constituted the reference group. For example, children with at least one moderate or more severe (AIS2+)

skull/brain injury were compared with children without any skull/brain injury. An odds ratio less than one indicates a protective effect of the helmet. The occurrence of skull/brain and facial injuries was further analysed with multivariate binary logistic regression with respect to helmet use and demographic and crash-related factors. Stratified univariate analyses were carried out in order to examine further these relationships, with regard to age group, gender, time period, injury severity, type of crash, crash setting, type of place, and type of activity.

The injury pattern was described as the percentage of children with at least one injury of a specified severity to a specified body region. Head injuries were divided into injuries to the skull or brain and injuries to the face. Changes to the injury pattern during the period 1993-2006 were analysed with univariate binary logistic models with the accident year as the independent variable. Children with less severe injuries (than specified) to the body region constituted the reference group. For each body region, the odds of sustaining an injury of a specified severity were compared with the odds of sustaining a less severe injury during the next year. An odds ratio less than one indicate a decreasing risk of injury with time.

In the absence of exposure data, we used subjects with extremity injures as a measure of exposure to the risk of cycling trauma, as done by Povey et al. and Walter et al. [28,29]. The ratio of the number of subjects with head injuries to the number of subjects with extremity injuries of any severity and of at least moderate severity was used to estimate the protective effect of helmets at population level.

The statistical analyses were carried out using the IBM© SPSS©software, version 21. The chi-squared test was used in analyses with more than two subgroups, while the Fisher's exact test was used in the other analyses. All tests were two-sided and statistical significance was determined at $p<0.05$.

2.3 Subjects

A total of 4318 injured cyclists below the age of 16 were consecutively registered in 1993-2006 at Queen Silvia's Children Hospital at Sahlgrenska University Hospital in Gothenburg. All the cyclists were included, regardless of the scene of the crash (on or off-road), or the type of transport to the hospital (by ambulance or not). Of these, 72 children with unknown injuries were excluded, and the remainder constituted study group 1 (n=4246). The additional 547 children with unknown helmet use were excluded (12 cases with unknown injuries), and the rest made up study group 2 (n=3711). Group 1 was used for description of the injuries and Group 2 for investigation of helmet use and the protective effect of helmets against head injuries.

Table 1 shows demographic and crash characteristics for study group 2 with respect to helmet use. The majority (64 %) of the children only had minor injuries. The following differences were noted between the excluded cases (n=607) and the study groups: Children excluded from Group 1 were older (58 % were at least 10 years old vs. 51 % of the total, p=0.001), and more often injured in crashes with a counterpart (22 % vs. 14 %, p= <0.001). The children excluded from Group 2 (n=535) had fewer AIS2+ skull/brain injuries (7.1 % vs. 9.8 %, p=0.048) and AIS1+ facial injuries (26.7 % vs. 32.4 %, p=0.008). No difference was found regarding AIS3+ skull/brain injuries or AIS2+ facial injuries.

Table 1. Demographic and crash characteristics of study Group 2 by helmet use, n=3711.

	No helmet		Helmet		
Factor	n	%	n	%	p value
Gender					
Male	1040	*66.5*	1326	*61.8*	0.004[1]
Female	525	*33.5*	820	*38.2*	
Age (y), male					
0-3	21	*2.0*	42	*3.2*	<0.001 df=4 Chi2=290
4-6	133	*12.8*	390	*29.4*	
7-9	150	*14.4*	332	*25.0*	
10-12	284	*27.3*	372	*28.1*	
13-15	452	*43.5*	190	*14.3*	
Age (y), female					
0-3	16	*3.0*	26	*3,2*	<0.001 df=4 Chi2=196
4-6	102	*19.4*	291	*35.5*	
7-9	86	*16.4*	226	*27.6*	
10-12	145	*27.6*	231	*28.2*	
13-15	176	*33.5*	46	*5.6*	
Type of crash					
Single	1311	*83.8*	1873	*87.3*	0.005 df=4 Chi2=15
Against cyclist	115	*7.3*	151	*7.0*	
Against car	94	*6.0*	78	*3.6*	
Other	41	*2.6*	40	*1.9*	
Unknown	4	*0.3*	4	*0.2*	
Type of crash place					
Bicycle- or walking lane	350	*22.4*	608	*28.3*	<0.001 df=4 Chi2= 34
Road	607	*38.8*	711	*33.1*	
Yard/private	301	*19.2*	441	*20.5*	
Other	162	*10.4*	252	*11.7*	
Unknown	145	*9.3*	134	*6.2*	
Type of activity					
Leisure time	1348	*86.1*	1847	*86.1*	0.8 df=3 Chi2=1.1
To/In/From school	173	*11.1*	227	*10.6*	
Other	9	*0.6*	13	*0.6*	
Unknown	35	*2.2*	59	*2.7*	
Crash setting					
In Gothenburg	1111	*71.0*	1351	*63.0*	<0.001 df=2 chi2=28.4
Outside Gothenburg	419	*26.8*	751	*35.0*	
Unknown	35	*2.2*	44	*2.1*	
Period					
1993-1999	990	*63.3*	1061	*49.4*	<0.001[1]
2000-2006	575	*36.7*	1085	*50.6*	
Care					
Outpatient	1179	*75.3*	1715	*79.9*	0.001[1]
Inpatient	386	*24.7*	431	*20.1*	

[1]Fisher's Exact Test.

3 RESULTS

3.1 Helmet use by gender and age

Helmet use in study group 2 varied with respect to demographic and crash-related factors (Table 1). It increased from about 40 % to about 80 % from 1993 to 2006, almost equally for boys and girls, and remained quite stable, about 60 %, during the period 1997-2003. It increased from 63 % during 2003-2004 to 78 % during 2005-2006, after adoption of the law on helmet use (p<0.001). Helmets were used by over 60 % of those below 11 years of age but significantly less often by teenagers, especially girls (Figure 1, Table1). The same low helmet use by teenagers was seen during the two periods 1993-1999 and 2000-2006.

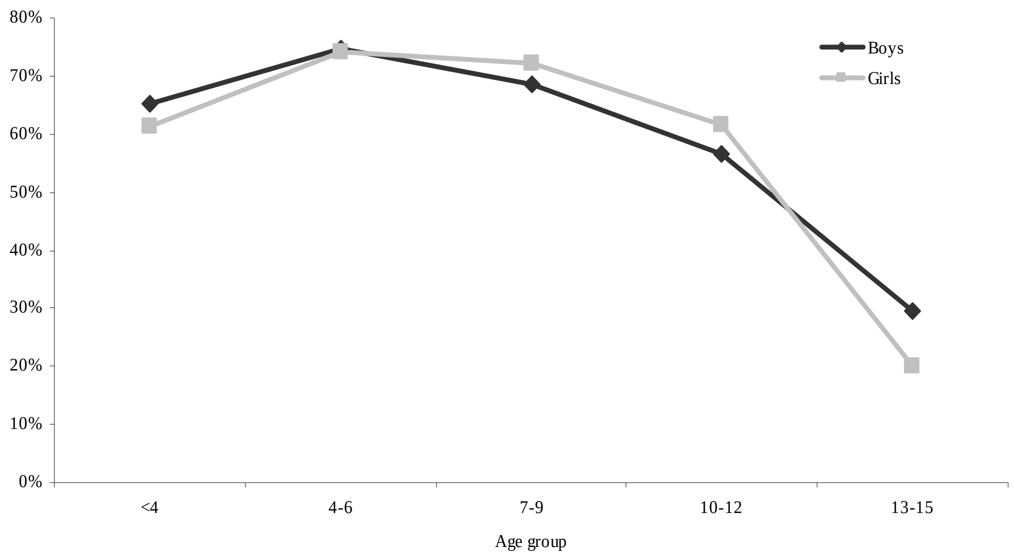

Figure 1. Helmet use by gender and age group in 3711 children (Group 2) injured during 1993-2006.

3.3 Helmet use and skull/brain and facial injuries

Skull/brain injuries of all severities and non-minor facial injuries (AIS2+) were significantly less frequent in helmeted cyclists in the univariate analyses (Table 2).

Table 2. Occurrence of injury and injury severity in skull/brain and facial injuries with and without a helmet, n=3711 (Group 2).

Body region Injury severity[2]	No helmet n	No helmet %	Helmet n	Helmet %	OR[1]	95% CI Lower	95% CI Upper	p value
Skull/brain								
MAIS1+	353	*22.6*	270	*12.6*	0.494	0.415	0.588	<0.001
MAIS2+	206	*14.5*	157	*7.7*	0.492	0.395	0.613	<0.001
MAIS3+	16	*1.3*	8	*0.4*	0.323	0.138	0.757	0.010
MAIS4+	8	*0.7*	2	*0.1*	0.162	0.034	0.762	0.018
Face								
MAIS1+	489	*31.2*	713	*33.2*	1.095	0.952	1.259	0.214
MAIS2+	17	*1.6*	6	*0.4*	0.265	0.104	0.674	0.005
MAIS3+	1	*0.1*	1	*0.1*	0.751	0.047	12.018	1.000

[1] OR<1 indicates a protective effect of a helmet.
[2] The figures represent the number and proportion in each group with at least one injury of the specified severity in the body region. The remaining children have no injury at all in the region.

Separate analyses were made for those 2276 children who were injured on a street/road or on a bicycle/walking lane. The odds for non-minor (AIS2+) skull/brain injuries for helmeted cyclists was 0.491 (P<.001; 95 % CI: 0.339-0.712) of that for non-helmeted cyclists in those injured on a road/street and 0.598 (P=0.022; 95 % CI: 0.387-0.925) of that in those injured on a bicycle/ walking lane (not shown in Table 2). Of all 21 children with AIS3+ skull/brain injuries, five were injured off road. The odds for non-minor (AIS2+) facial injuries in helmeted children was 0.114 (P=0.027; 95 % CI: 0.013-0.927) of that for non-helmeted children injured on walking/bicycle lanes. Seven children sustained AIS2+ facial injuries in crashes on a street/road; three of them used a helmet.

The protective effect of a helmet against non-minor skull/brain and facial injuries remained significant in multivariate binary logistic regression models (Table 3). The models also showed a protective effect of helmets against AIS1+ facial injuries, decreasing odds for facial injuries with age, and greater odds for AIS3+ skull/brain injuries during the latter half of the period and in crashes with a motor vehicle (Table 3).

Table 3. The association between personal characteristics and crash factors and the injury severity of skull/brain and facial injuries n=3711 (study Group 2).

	Skull/brain injury		Facial injury	
	AIS2+ (n=326)	AIS3+ (n=22)	AIS1+ (n=1113)	AIS2+ (n=21)
Factors	OR (95%CI)	OR (95%CI)	OR (95%CI)	OR (95%CI)
Used helmet	0.45 (0.35-0.58)*	0.26 (0.10-0.69)*	0.75 (0.63-0.88)*	0.23 (0.09-0.63)*
Female gender	1.08 (0.85-1.38)	1.98 (0.84-4.67)	1.01 (0.87-1.18)	1.01 (0.41-2.49)
Age, per year	0.97 (0.93-1.00)	1.01 (0.88-1.16)	0.86 (0.84-0.88)*	0.86 (0.76-0.98)*
Latter period	1.04 (0.82-1.33)	3.82 (1.44-10.11)*	0.99 (0.85-1.16)	0.86 (0.33-2.21)
In Gothenburg	0.85 (0.66-1.09)	0.56 (0.24-1.34)	1.14 (0.97-1.34)	1.71 (0.56-5.19)
Against motor vehicle	1.50 (0.97-2.32)	4.76 (1.74-13.03)*	1.11 (0.81-1.53)	0.89 (0.12-6.87)
Bicycle/walking lane	1.06 (0.81-1.38)	0.60 (0.20-1.83)	1.27 (1.07-1.50)*	1.32 (0.50-3.50)

*p<0.05.

Stratified analyses were performed to explore further the effect of helmet use on certain injuries within factors such as gender, age group, accident type, accident place and period. The protective effect of helmets against non-minor (AIS2+) skull/brain and facial injuries was consistently seen to be greater for girls, at higher age, and during the period from the year 2000 (results not shown). The occurrence of AIS2+ skull/brain injuries in crashes with a motor vehicle (191 cases) was lower in helmeted (10/89=11.2 %) than in non-helmeted cyclists (18/102=17.6 %) in these analyses, but the difference was not statistically significant (p=0.2). None of 79 helmeted cyclists and six out of 90 non-helmeted cyclists sustained AIS3+ skull/brain injuries in a crash with a motor vehicle (all on-road accidents). All six were injured during the second period. We also made stratified analyses using the same model as in Table 3 for the subgroup injured during the second period (n=1277). Collision with a motor vehicle remained a significant risk factor and the helmet a significant protective factor with regard to serious or more severe (AIS3+) skull/brain injuries.

3.4 Injury patterns – changes during 1993-2006

The children most frequently received injuries to the head (skull/brain or face) and the extremities (Figure 2), with the most severe injuries (AIS4+) to the brain (10 children) and the lower trunk (5 children).

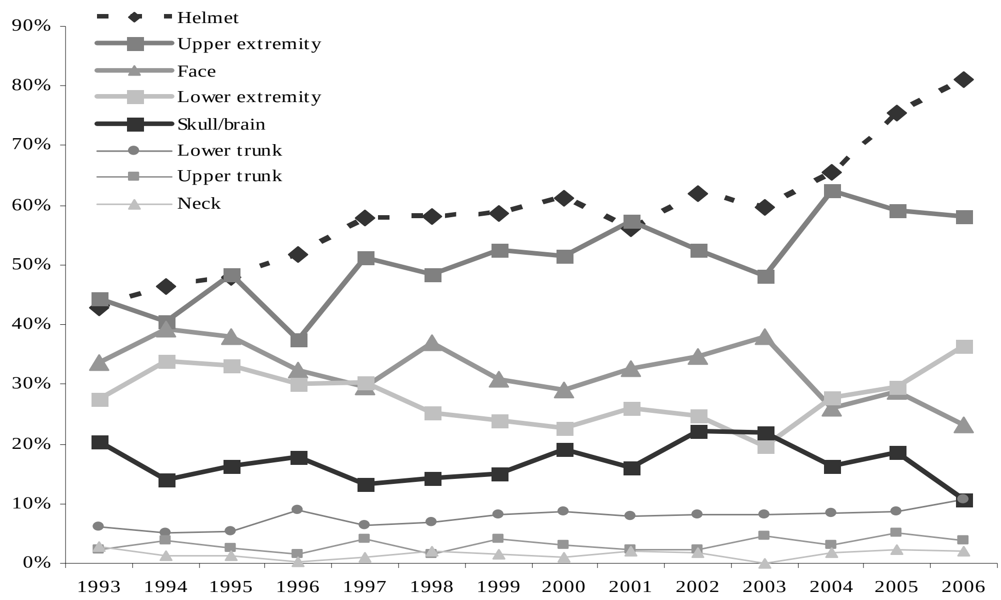

Figure 2. Helmet use and injury patterns 1993-2006. The dashed line shows the proportion of 3711 injured children with a helmet (Group 2) and the other lines the proportion of 4246 children (Group 1) with at least one injury of any severity in the specified body region.

Injuries to the lower trunk were noted in less than ten per cent of the children, as were injuries to the upper trunk and the neck (Figure 2). The proportion with skull/brain injuries of any severity (14 % – 20 %) did not change significantly during the period (Figure 2, Table 4). The proportion with upper extremity injuries of any severity increased from 44 % to 58 % and the proportion with facial injuries of any severity decreased from 34 % to 23 %.

Table 4. Changes to injury patterns in 4246 children in study Group 1 during 1993-2006.

	AIS of any grade			AIS2+			AIS3+		
		OR[1] 95% CI			OR[1] 95% CI			OR[1] 95% CI	
Body region	OR[1]	Lower	Upper	OR[1]	Lower	Upper	OR[1]	Lower	Upper
Skull/Brain	.998	.977	1.019	.972*	.946	.998	1.170*	1.059	1.293
Face	.964*	.948	.980	.851*	.759	.954	.841	.563	1.256
Neck	1.032	.970	1.098	1.274	.937	1.732	1.472	.934	2.318
Upper extremity	1.059*	1.043	1.076	1.063*	1.042	1.085	1.182*	1.141	1.225
Upper trunk	1.040	.995	1.087	1.218*	1.024	1.449	1.193	.979	1.454
Lower trunk	1.043*	1.013	1.073	1.001	.924	1.086	1.085	.915	1.287
Lower extremity	.988	.971	1.005	.906*	.871	.941	1.035	.945	1.134

* p<0.05.
[1] OR equals the odds of sustaining at least one injury of the specified severity to the body region during the next year compared with the odds of sustaining a less severe injury to the region.

The proportion with moderate or more severe (AIS2+) injuries increased for the upper extremity and the upper trunk and decreased for the skull/brain, the face, and the lower extremity (Table 4). The proportion with AIS2+ injuries to the upper trunk was less than one per cent during the whole period. The proportion with AIS2+ injuries to the upper extremity reached 25 % during 2005. The proportion with serious or more severe (AIS3+) injuries increased for the skull/brain and the upper extremity (Table 4).

The occurrence of head injuries (AIS1+, AIS2+, AIS3+) did not change significantly during the periods 2003-2004 and 2005-2006; i.e., two years before and after the introduction of the law on helmet use.

According to similar analyses for different age groups, the proportion with facial injuries of any severity decreased for children 10-12 years of age (p=0.001; OR=0.938; 95% CI: 0.903-0.975 per year). A decrease was also seen for non-minor facial injuries in this age group, but this was not statistically significant (p=0.10; OR=0.814; 95% CI: 0.636-1.041 per year). The proportion with serious injuries to the upper extremities increased significantly for all age groups except for children below four years of age. Significant changes were not noted for specific age groups for the other body regions.

The ratio between the number of children with head injuries and the number with extremity injuries decreased during 1993-2006 for injuries of any severity and for moderate or more severe injuries (Figure 3).

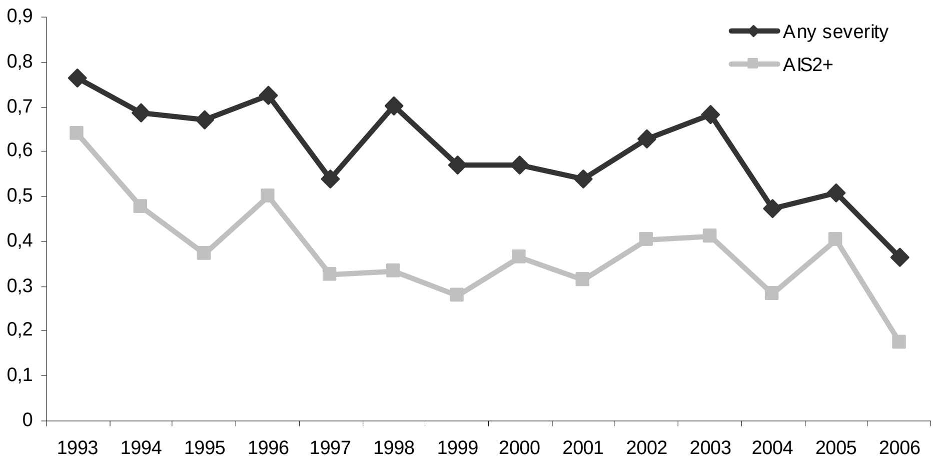

Figure 3. The ratio between the number of children with head injuries and the number of children with extremity injuries during 1993-2006, n= 4246 (Group 1). The two lines represent injuries of any severity and at least moderate severity (AIS2+).

4 DISCUSSION

As cyclists nowadays constitute the largest group of severely injured road users in Sweden, and children most often are injured as cyclists, all attempts to minimise their risk of being injured during cycling are justified. Cyclist injuries are most frequently localised to the head and upper extremities, as are the more severe injuries. The results of this study indicate a significant protective effect of a helmet against skull/brain and facial injuries of all severities, and the effect increased with the severity of the injury. The use of helmets increased in the study group; also before helmet use was made mandatory for children below 16 years of age. Nevertheless, teenagers in the study group, especially girls, used bicycle helmets much less often than younger children, also after the helmet law was introduced, and targeted information about the high risk of head injuries in bicycle crashes without a helmet appears to be needed for this category. Teenagers may not identify themselves as children but as adults, and there is no law on helmet use for adults. The increasing proportion of non-minor injuries to the upper extremities in the study group should also be noted.

4.1 Helmet use and skull/brain injuries

The adjusted odds of serious or more severe (AIS3+) skull/brain injuries with a helmet in our study were about one fourth of the odds without a helmet (Table 3). The protective effect of a helmet against skull/brain injuries of less severity was somewhat smaller in univariate analyses (Table 2), but was almost the same when off-road accidents were excluded. McDermott et al. [27] reported lower head AIS scores in users of approved helmets in children under 18. Other studies did not report on the risk of head injuries and injury severity [10,11,34,35], did not assess the injury severity according to AIS [12,16,26], or did not report the children separately [13-15,36,37]. According to Persaud et al. [14], not wearing a helmet while cycling was associated with an increased risk (adjusted OR 3.1) of dying as a result of a head injury (not only children). Amoros et al. [15] presented a study including 8373 subjects (2990 children). The fully adjusted OR for AIS3+ head injuries in helmeted versus non-helmeted cyclists in urban areas was 0.34. Thompson et al. [36] examined the protective effect of bicycle helmets in 3390 injured cyclists (1468 children <15). The OR for serious or more severe brain injuries (AIS3+) was 0.26 for helmeted versus non-helmeted cyclists, adjusted for age and motor vehicle involvement (5 children 6-12). Ji et al. [37] investigated head injuries in 1116 trauma patients (510 children <18). The OR for AIS3+ head injuries was 0.43 in helmeted versus non-helmeted cyclists after adjusting for age, ethnicity and time [37]. Other factors in our study associated with serious or more severe skull/brain injuries in the multivariate analyses were ‘the latter half of the period’ and ‘crash with a motor vehicle’. In the stratified analysis, helmets had a significant protective effect against AIS3+ skull/brain injuries in crashes with a motor vehicle during the latter half of the period; however, the OR for this subgroup could not be calculated, as none of these children used a helmet. The Cochrane review [8] (not only children) shows an equal protective effect of a helmet in crashes involving motor vehicles (69 %) and other crashes (68 %). Bambach et al. [13] examined the effect of helmets on 6745 cyclists (684 children <13) in crashes involving motor vehicles. Helmet use was associated with a reduced risk of head injuries of up to 74 %, and the more severe the injury, the greater the reduction. Amoros et al. [15] could not find any difference in helmet protection in bicycle crashes with or without motor vehicle involvement. Larsen et al. [10] reported a protective effect of helmets in a study including 3285 children. Helmet use decreased the risk of head injuries (OR=0.4); however, this effect could not be shown in crashes with motor vehicles, probably, according to the author, due to the small number of cases. The protective effect of a helmet against skull/brain injuries in all types of bicycle crashes found in the present study was considerable and in accordance with most other studies.

4.2 Helmet use and facial injuries

Helmets protected against facial injuries in the present study. This is in accordance with other studies [11,12,15,27,38,39]. Amoros et al. [15] reported a fully adjusted OR=0.72 for AIS1+ facial injuries (not only children). McDermott et al. [27] found a 28% lower frequency of facial injuries and significantly lower AIS scores in wearers of approved helmets than in non-helmeted cyclists (not only children). Heng et al. [12] reported facial injuries in 5.9 % of cyclists with helmets and in 37.1 % of those without. Hansen et al. [8] could not demonstrate a reduced risk of facial injuries among users of hard shell helmets compared with patients with cycle-related injuries, apart from head and facial injuries. Two studies by Thompson et al. [38,39] found a protective effect against serious injuries to the upper part of the face but not to the lower part. We did not analyse which part of the face was injured. It seems reasonable that helmets covering a greater area of the face and more protruding helmets would provide better protection against facial injuries. It may also be important to wear the helmet properly attached, sufficiently far down on the forehead.

4.3 Injury patterns – changes during 1993-2006

The injury patterns changed during the period with a decreasing proportion of non-minor head (skull/brain or face) injuries and an increasing proportion of upper extremity injuries. In order to estimate the protective effect of helmets against head injuries at population level in the absence of exposure data, we used subjects with extremity injures as a measure of exposure to the risk of cycling trauma. The ratio of the number of subjects with head injuries (likely to be affected by helmet wearing) to the number of subjects with extremity injuries (unlikely to be affected by helmet wearing) decreased. This may indicate a protective effect of bicycle helmets in the population. Walter et al. [29] assessed the effect of mandatory bicycle helmet legislation on cyclist head injuries (adults and children), given the ongoing debate in Australia, with regard to the efficacy of this measure at population level. They used hospital admission data from a 36-month period centred at the time when the legislation came into force. To avoid the issue of the lack of cyclist exposure data, they assumed equal exposure for head and limb injuries, which allowed for an arbitrary proxy exposure to be used in the model. As a comparison, analyses were performed also for pedestrian data to identify which of the observed effects were specific to cyclists. Head injury rates decreased significantly more than limb injury rates at the time of introduction of the legislation among cyclists but not among pedestrians [29]. Povey et al. [28] also used cyclist limb injuries (fractures) as a measure of exposure to the risk of cycling trauma (adults and children) during a period of increasing helmet use in New Zeeland between 1990 and 1996. Bicycle helmet wearing became mandatory under New Zealand law in January 1994. Cyclist head injuries decreased with increasing helmet-wearing rates in all types of cycle crashes. No increase or decrease in the severity of head injuries for which cyclists were hospitalised over this period could be detected, probably, according to the authors, due to the small and highly variable number of “high severity” injuries [28].

The increasing occurrence of moderate or more severe injuries to the upper extremities, but not to the lower extremities, was not expected; however, there are many factors that may influence the injury risk. These include the risk of being involved in a crash and the risk of being injured in the crash. Risk compensation may be important, but some studies on this topic are contradictory. Phillips et al. [20] showed decreased cycling speed and increased risk perception in routine helmet users when they did not wear a helmet. Pless et al. [23] found no association between indicators of risk-taking behaviour and the use of protective equipment. Bambach et al. [13] reported non-helmeted cyclists to be more likely to display risky riding behaviour, but less likely to cycle in risky areas and more likely to be seriously injured in other body regions than the head. Lasenby-Lessard et al. [40] found that children (cycling, rollerblading) show risk compensation when wearing safety gear and the extent varied, based on the level of experience and their level of sensation-seeking.

More advanced bicycle models may have been used during the second period during which helmets were used by a higher proportion of cyclists. Modern bicycles may stimulate or enable faster riding and more risky behaviour. As cyclists may try to protect their head when falling, injuries to the upper extremities could be expected. Information about the increasing risk of arm injuries in children in bicycle crashes is needed, as well as development of protective equipment, like that for motorcyclists and users of roller blades and mountain bikes. Further studies on this topic are recommended, including on risk compensation.

4.4 Strengths and limitations

We consider the internal validity of this study to be good, as helmet use was assessed at the time of the crash. Furthermore, all injuries were classified in a standardised way on the basis of medical records. The same well-trained staff members were responsible for both recording and injury classification, and the same AIS system was used during the whole period 1993-2006.

Children without injuries and with injuries not leading to visiting an A&E ward were not included, so we can only describe the effect of helmets in a subgroup of children. On the other hand, the large sample means that we can control for several confounding factors.

By relating the number of children with head injuries to the number with extremity injuries, the protective effect of helmets in the general population seems obvious.

We have not investigated the type of brain injury or the type of helmet, and we cannot draw any conclusions about the risk of brain injury from different types of impact. The injury risk was graded according to the AIS, which predicts the fatality risk and not the risk of permanent impairment. It seems reasonable, however, that the protective effect of a helmet against brain injuries would also be expected to apply to brain injury sequelae. As excluded cases with missing data on helmet use or injury severity amounted to only 14 % of the total sample, we do not believe that differences between the study groups and the excluded cases have had any significant influence. The excluded children were older and more often injured in crashes with a counterpart. As older children used helmets less often than younger children, it is reasonable to assume that the excluded children also used helmets less often. Excluded children with known injuries, where helmet use was not known, had fewer AIS2+ skull/brain injuries and AIS1+ facial injuries, and this may weaken our results if a majority of them did not use a helmet. However, as no difference was found for AIS3+ skull/brain injuries or AIS2+ facial injuries, we believe our results to be reliable.

We did not analyse the effect of the helmet use legislation on the injuries separately, as the law was in force during only two years of the study period.

CONCLUSIONS

Bicycle helmets have an obvious protective effect against head and facial injuries in cycle crashes, regardless of the crash circumstances. The great risk of serious or life-threatening head injuries without helmet use should be emphasised, especially to teenagers. Attention should be paid to the increasing occurrence of non-negligible injuries to the upper extremities and preventive measures should be taken. Future studies on bicycle safety should include risk compensation.

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CONFLICT OF INTERESTS

None declared.

ABBREVIATIONS

A&E	Accident and Emergency
AIS	Abbreviated Injury Scale
CI	Confidence Interval
ICD	International Classification of Diseases
MAIS	Maximum AIS
OR	Odds Ratio
SPSS	Software Package used for Statistical analysis
STRADA	Swedish Traffic Accident Data Acquisition

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