Bicycle helmets and injury prevention:
A formal review

Robyn Attewell
Kathryn Glase
Covance Pty Ltd

Michael McFadden
ATSB

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Authors

R Attewell (Covance)
K Glase (Covance)
M McFadden (ATSB)

Performing Organisation

Statistical Services
Covance Pty Ltd
PO Box 64
AINSLIE ACT 2602

Sponsored by / Available from

Australian Transport Safety Bureau
PO Box 967
CIVIC SQUARE ACT 2608

Abstract

Australia is one of the few countries with current uniform helmet legislation (introduced in the early 1990s), but many cyclists continue to ride without head protection. Many peer-reviewed epidemiological studies published over the past decade have investigated the efficacy of helmets in preventing serious injury to bicycle riders involved in crashes. This report presents a formal summary quantification of these results and provides overwhelming evidence in support of helmets for preventing head injury and fatal injury.

Keywords

BICYCLE HELMET, HEAD INJURY, BRAIN INJURY, INJURY PREVENTION, META-ANALYSIS

NOTES:

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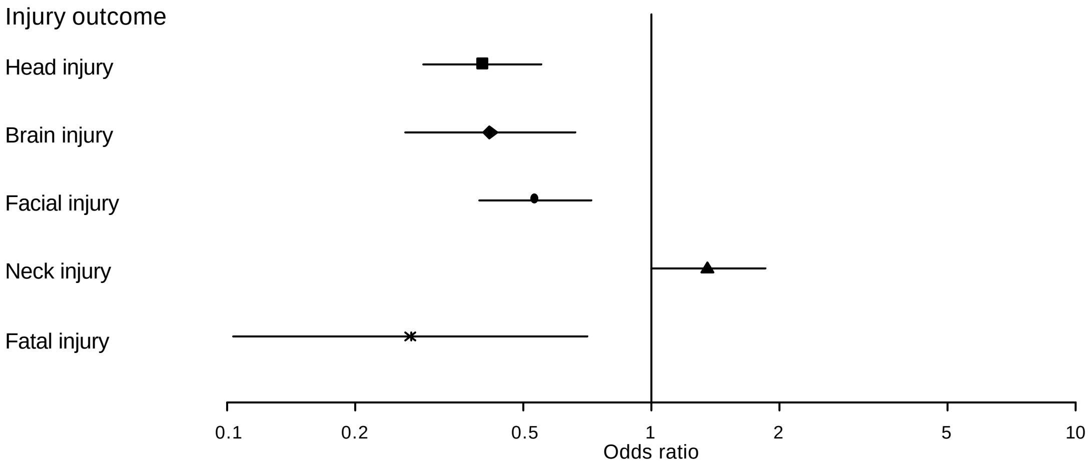
EXECUTIVE SUMMARY

In this report, bicycle helmet efficacy is quantified using a formal meta-analytic approach based on peer-reviewed studies. Though several reviews have already been published advocating the use of helmets, this approach provides summary estimates of efficacy in terms of head injury, brain injury and facial injury based on studies of cyclists involved in crashes in which injury and helmet information is available for each individual. It also provides evidence concerning neck injury and fatal injury. These topics have only been partially addressed previously due to the small numbers of cases involved.

The results are based on studies conducted in Australia, the USA, Canada and the United Kingdom, published in the epidemiological and public health literature in the period 1987-1998. The summary odds ratio estimate for efficacy is 0.40 (95% confidence interval 0.29, 0.55) for head injury, 0.42 (0.26, 0.67) for brain injury, 0.53 (0.39, 0.73) for facial injury and 0.27 (0.10, 0.71) for fatal injury. This indicates a statistically significant protective effect of helmets. Three studies provided neck injury results that were unfavourable to helmets with a summary estimate of 1.36 (1.00, 1.86), but this result may not be applicable to the lighter helmets currently in use.

In conclusion, the evidence is clear that bicycle helmets prevent serious injury and even death. Despite this, the use of helmets is sub-optimal. Helmet use for all riders should be further encouraged to the extent that it is uniformly accepted.



1. Background

Australia was the first country to introduce compulsory bicycle helmet legislation in the early 1990s. New Zealand followed in 1994. Only some jurisdictions in the USA have equivalent legislation. There is no current legislation in the United Kingdom despite support from the medical community. There is extensive literature supporting the use of helmets, including experimental, population based and individual efficacy studies. Reviews by Henderson (1995), Thompson and Patterson (1998) and Rivara et al (1998) all concluded that helmets are effective and endorsed legislation, but none included a formal meta-analysis. There are also numerous articles in the literature that do not advocate helmet use for cyclists. Additionally, there is debate as to the efficacy of helmets in preventing brain injury and facial injury as well as head fractures. This report addresses the quantification of the efficacy of helmet use in preventing different types of serious injury to cyclists via a formal meta-analytical approach.

2. Method

Meta-analysis

Meta-analysis is a statistical tool for combining the results of multiple studies. The aim of a meta-analysis is to calculate a single summary estimate of a quantity by combining estimates from numerous similar separate studies. Most importantly, it also provides an estimate of the variation in the summary estimate based on the estimates of variation from the individual studies.

The major benefit of meta-analysis is that it allows smaller studies, which on their own may not be of sufficient size to produce a valid conclusion, to contribute to the body of evidence relating to a certain research question. In addition, it provides a more formal and rigorous structure for evaluating evidence than the traditional narrative literature review which can be selective in inclusion of studies and subjective in weighting of studies (Petitti, 1994).

A disadvantage of meta-analysis (which is common to all retrospective reviews) is that it is limited to those studies that have been conducted, published and located in the literature search. Articles still in preparation or review will be missed. The exclusion of articles never submitted or already rejected for publication is referred to as publication bias, ie when papers are rejected on the basis of having of non-statistically significant results. This will only be substantive if either the number of studies rejected is large or they contain large numbers of subjects. This is unlikely since these tend to be small studies.

The major criticism of meta-analysis is inclusion of studies that are too diverse to provide a meaningful summary statement. The challenge is to define inclusion and exclusion criteria that will adequately minimise variation in design, outcome measure, population and quality. In this regard, the accuracy and level of detail in the original paper may restrict the assessment.

Literature search

The meta-analysis described in this report was conducted by first undertaking a literature search to identify potentially relevant articles. The search was limited to published studies. No attempt was made to identify and include unpublished or “fugitive literature”. The literature search was conducted using MEDLINE (a computerised bibliographic database of biomedical literature). The search was not limited by publication year. Search keywords included *bicycle helmet*, *efficacy* and *head injury*. The Helmet Resource Database was also searched. The Helmet Resource Database is an enterprise of the World Health Organisation Helmet Initiative, and contains information on helmet effectiveness, helmet promotion, helmet design and standards and helmet legislation. Review article references were used as an additional source. The search was initiated in October 1998 and regularly updated until August 1999. The abstracts of each journal article were examined to determine suitability for inclusion in the review.

The search produced 63 articles that were considered potential candidates for inclusion (Table 1). Copies of all these papers were obtained and an initial review was conducted to determine which data were sufficiently common across all publications to warrant extraction. Due to the large number of articles, an extraction form was developed so that a structured summary could be compiled for each article (see below). This was done by two extractors working independently. Blinding to authors and sources was not implemented. The summaries were compared and discrepancies were resolved by joint referral to the original publication.

Extraction form

Author
Title
Year
Journal
Country
Design
Outcome
Subjects
Helmet use
Helmet type
Results
Comments
Extracted data
Study conclusion

Table 1. Journal articles accessed for study

No.	Author(s)	Published	In/out	Details/reason for exclusion
1	Acton	1995	Exclude	Letter to the editor, no new data
2	Acton	1997	Exclude	Letter to the editor, no new data
3	Acton et al	1996	Exclude	Incompatible design, insufficient detail
4	Acton et al	1995	Exclude	Incompatible design, insufficient detail
5	Bjornstig et al	1992	Exclude	Incompatible design, insufficient detail
6	Cameron et al	1994	Exclude	Incompatible design, population study
7	Carlin et al	1998	Exclude	Incompatible design, outcome and objective
8	Ching et al	1997	Exclude	Incompatible design, all subjects wore helmets
9	Colson	1997	Exclude	Letter to the editor, no new data
10	Council on Scientific Affairs AMA	1994	Exclude	Review article, no new data
11	Cushman et al	1990	Exclude	Incompatible design, insufficient detail
12	**Dorsch et al**	**1987**	**Include**	**Skull fractures, brain injury, facial fractures self report**
13	**Finvers et al**	**1996**	**Include**	**Serious head injury A&E presentation**
14	Grimard et al	1995	Exclude	Incompatible design, all subjects sustained head injury
15	Harrison & Shepherd	1997	Exclude	Laboratory study
16	Illingworth	1992	Exclude	Opinion piece, no new data
17	**Jacobson et al**	**1998**	**Include**	**Head injury A&E presentations**
18	Kennedy	1996	Exclude	Incompatible design, no subjects wore helmets
19	Kraus et al	1987	Exclude	Incompatible design, no helmet use data
20	Lane & McDermott	1993	Exclude	Review, no new data
21	Lane & McDermott	1994	Exclude	Letter to the editor, no new data
22	**Linn et al**	**1998**	**Include**	**Head, brain injury A&E ICU presentations**
23	**Maimaris et al**	**1994**	**Include**	**Head, face/neck A&E**
24	Martinez	1994	Exclude	Editorial, no new data
25	McCarthy	1992	Exclude	Opinion piece, no new data
26	McDermott	1992	Exclude	Review, no new data
27	McDermott	1997	Exclude	Letter to the editor, no new data
28	**McDermott et al**	**1993**	**Include**	**Head, face, neck injury A&E and fatalities**
29	McIntosh et al	1998	Exclude	Incompatible design, all subjects wore helmets
30	Mills & Gilchrist	1991	Exclude	Laboratory study
31	Ozanne-Smith & Sherry	1990	Exclude	Incompatible design, population study, non-peer reviewed
32	Pitt et al	1994	Exclude	Incompatible design, population study
33	Povey et al	1999	Exclude	Incompatible design, population study
34	Resnick et al	1995	Exclude	Letter to the editor, incompatible design (test fit of helmet)
35	**Rivara et al**	**1997**	**Include**	**Neck injury A&E and fatalities**
36	Robinson	1996	Exclude	Incompatible design, population study
37	Robinson	1997	Exclude	Letter to the editor, incompatible design, population study
38	Robinson	1997	Exclude	Letter to the editor, incompatible design, population study
39	Ryan	1992	Exclude	Review article, no new data
40	Sacks et al	1991	Exclude	Incompatible design, estimates preventable injuries
41	Scuffham & Langley	1997	Exclude	Incompatible design, population study
42	**Shafi et al**	**1998**	**Include**	**Head & brain injury admitted to trauma centre & fatalities**
43	Simpson & McLean	1997	Exclude	Letter to the editor, no new data
44	Smith et al	1994	Exclude	Laboratory study
45	Sosin et al	1996	Exclude	Incompatible design, estimates preventable injuries
46	**Spaite et al**	**1991**	**Include**	**Head injury A&E and fatalities**
47	**Thomas et al**	**1994**	**Include**	**Head & brain injury A&E**
48	Thompson	1994	Exclude	Letter to the editor, no new data
49	**Thompson, Nunn et al**	**1996**	**Include**	**Facial injury A&E**

continued

Table 1. Journal articles accessed for study (*continued*)

No.	Author(s)	Published	In/out	Details/reason for exclusion
50	Thompson & Patterson	1998	Exclude	Review, no new data
51	**Thompson, Rivara et al**	**1996**	**Include**	**Head & brain injury A&E and fatalities**
52	**Thompson et al**	**1990**	**Include**	**Facial injury A&E**
53	**Thompson et al**	**1989**	**Include**	**Head & brain injury A&E and fatalities**
54	Trippe	1992	Exclude	Opinion piece, no new data
55	Vulcan et al	1992	Exclude	Incompatible design, population study
56	**Wasserman & Buccini**	**1990**	**Include**	**Head, brain, face & neck injury self report**
57	**Wasserman et al**	**1988**	**Include**	**Head & brain injury self report**
58	Weiss	1991	Exclude	Editorial, no new data
59	Welander et al	1999	Exclude	Incompatible design, population study
60	Williams	1990	Exclude	Incompatible design, laboratory study
61	Williams	1991	Exclude	Incompatible design, laboratory study
62	Wood & Milne	1988	Exclude	Incompatible design, population study
63	Worell	1987	Exclude	Incompatible design, no subjects wore helmets

Protocol

The 63 articles covered a diverse range of designs including experimental studies of new helmets, laboratory examinations of damaged helmets, population level studies comparing trends in helmet use and injury prevalence and studies of individual cyclists involved in crashes. There were also review articles, editorials, letters and opinion pieces. They are listed alphabetically by first author in Table 1. This was reduced to a subset suitable for final inclusion in a formal meta-analysis based on the following inclusion criteria:

- English language publication
- Peer reviewed published study
- Studies based on individual cyclists
- Data to complete a 2 x 2 table of injury (yes/no) by helmet use(yes/no), that is, studies had a helmeted and an unhelmeted group and included injured and uninjured persons
- Studies reported at least one of the outcome measures – head injury, brain injury or facial injury.

Articles that fulfilled these criteria, but that were a subpart of a larger study were excluded from the meta-analysis. Studies that failed to meet any of these criteria were excluded from analysis.

Statistical methods

The measure of efficacy used to compare the likelihood of injury to helmeted and unhelmeted cyclists is the odds ratio for helmeted versus unhelmeted riders. An odds ratio less than one is interpreted as evidence for a protective effect of helmets, ie the likelihood of injury is less if a helmet is worn. The odds ratio is the comparative measure most appropriate for use in case-control studies in which the subjects are selected based on their health outcome (ie injured or not) and then their exposure status (helmet worn or not) is determined. Most of the studies included in the meta-analysis are of this design.

Inference is drawn from the study subjects to the broader population of cyclists by calculating estimates of variation in odds ratios (standard errors) and then confidence intervals for the odds ratios. A confidence interval indicates the degree of precision associated with the odds ratio. Wide confidence intervals indicate there is less precision associated with the estimate. The usual method is to calculate a 95% confidence interval about an estimate. This indicates the range of efficacy about which one is 95% confident. A protective effect is interpreted as statistically significant if the upper bound of the 95% confidence interval is less than one.

The meta-analysis produces a single odds ratio estimate and an associated confidence interval that combines the individual odds ratio estimates and the standard errors from each individual study. More details on odds ratios, confidence intervals and meta-analysis are given in Appendix A.

Publication bias refers to the greater likelihood of publication of studies that produce statistically significant results. Publication bias was investigated using funnel plots (Petitti, 1994). These were constructed by plotting the precision of each study estimate against the estimate; in this case, 1/variance(ln(odds ratio)) vs odds ratio. The absence of publication bias is indicated by a scatter of points representing an inverted funnel centred on the average study estimate (ie narrow at the top representing the consistency of larger studies and broad at the base reflecting the expected heterogeneity of estimates from smaller studies). Publication bias is indicated by asymmetry in the scatter. In this case the right hand lower corner would be missing.

3. Results

Selected articles

Sixteen articles met the selection criteria of the protocol. These are highlighted in Table 1 and listed in chronological order of publication in Table 2. The main reason for exclusion was due to incompatible design (eg a laboratory or population study). There were also many letters and several reviews that contained no new data. Though published between 1987 and 1998, the reports are based on data collected from 1980 to 1995. Detailed structured study summaries of each of these articles are in Appendix B. The studies were published in a variety of journals including Accident, Analysis and Prevention (1), the British Medical Journal (2), the Journal of the American Medical Association (2), the American Journal of Public Health (2), the American Journal of Sports Medicine (1), the Clinical Journal of Sports Medicine (1), the Australian and New Zealand Journal of Public Health (1), the New England Journal of Medicine (1), Injury Prevention (2), the Journal of Trauma (2) and the Journal of Pediatric Surgery (1). The references for the 16 articles included in the meta-analysis are included in the general reference list at the end of this report. The references for the 47 articles excluded are in Appendix C.

Four of the studies include only children, but the others contain a high proportion of children reflecting the demographics of the cycling population. The studies vary in size from 21 to several thousand.

Table 2. Articles meeting selection criteria

Author(s)	Year	Country	Data	Age	Size	Head	Brain	Face	Neck	Death
Dorsch et al	1987	Australia	1980-85	Adult	197	Yes	Yes	Yes+	No	No
Wasserman et al	1988	US	1984	All	21	Yes[*]	Yes[✠]	No	No	No
Thompson et al	1989	US	1986-87	All	668	Yes	Yes	No	No	Yes
Thompson et al	1990	US	1986-87	All	531	No	No	Yes	No	No
Wasserman & Buccini	1990	US	1980-85	Adult	191	Yes[#]	Yes[✠]	Yes+	Yes	No
Spaite et al	1991	US	1986-89	All	284[★]	Yes	No	No	No	Yes
McDermott et al	1993	Australia	1987-89	All	1710	Yes	No	Yes	Yes	Yes
Maimaris et al	1994	UK	1992	All	1042	Yes	No	Yes[o]	Yes[o]	Yes
Thomas et al	1994	Australia	1991-92	Child	364	Yes	Yes	No	No	No
Finvers et al	1996	Canada	1991-93	Child	699	Yes[*]	No	No	No	No
Thompson, Rivara et al	1996	US	1992-94	All	3390	Yes	Yes	No	No	Yes
Thompson, Nunn et al	1996	US	1992-94	All	2909	No	No	Yes	No	No
Rivara et al	1997	US	1992-94	All	3384	No	No	No	Yes	Yes
Jacobson et al	1998	Australia	1991-92	All	229	Yes[*]	No	No	No	No
Linn et al	1998	Canada	1991-95	Child	1462	Yes[*]	Yes[✠]	No	No	No
Shafi et al	1998	US	1993-95	Child	208	Yes	Yes	No	No	Yes

★ all subjects involved in collision with a motor vehicle
* head and face
\# skull fractures only
✠ concussion
\+ facial fractures only
o face and neck combined

The earliest report was by Dorsch et al (1987) describing an Australian study of approximately 200 adults belonging to cycling clubs who replied to a mailed questionnaire concerning helmet use and injuries sustained in bicycle crashes over the past five years. The conclusion was that helmets reduce the severity of head injury based on crude analysis and multiple regression analysis adjusting for potential confounders such as age and sex of the riders and severity of the crash. There are two other self-report surveys included in the group of sixteen. These were conducted in the USA by Wasserman (1988, 1990). Despite the small size of the 1988 study (21 cyclists who reported falling and striking their heads in the past 18 months), there were statistically significant results in favour of helmets protecting against head injury. The 1990 study was of similar size to the Australian Dorsch study. It also concluded that bicycle helmets are effective in preventing head injuries.

All the other studies are based on cyclist presentations at hospital emergency departments after crashes. These studies have the advantage of a clinical definition of injury and possibly less scope for bias in reporting helmet use if it is done at the time of presentation. These studies were conduced in several countries, including Australia (McDermott et al, 1993; Thomas et al, 1994; Jacobson et al, 1998), Canada (Finvers et al, 1996 and Linn et al, 1998), the UK (Maimaris et al, 1994) and the USA (the remainder). Most of the papers from the USA are by the same research group, starting with a widely quoted paper by Thompson et al (1989).

The first two papers in the Thompson series report on a case-control study conducted in Seattle regarding the effectiveness of bicycle helmets in preventing head and brain injury (Thompson et al, 1989) and in preventing facial injury (Thompson et al, 1990). They concluded that bicycle helmets are highly effective in preventing head injury and, in particular brain injury and have some protective effect against serious upper facial injuries. The results were consistent with and without adjustment for age, sex, income, education, cycling experience and the severity of the accident. In addition, the results were consistent using both population-based controls (cyclists who had had an accident in the previous 12 months regardless of injury or medical care) and emergency room controls (those with non-head cycling injuries seen in an emergency room). The results were used in Sacks et al (1991) to estimate that one death could be prevented each day in the US and one head injury could be prevented every 4 minutes if helmets were universally worn by all bicyclists.

The next major contributions were three large case-control studies. Two of these were conducted in Australia, in Victoria by McDermott et al (1993) and in Queensland by Thomas et al (1994). The third was conducted in the UK by Maimaris et al (1994). The general design of these studies was similar to that of the Seattle study. All incorporated hospital controls as the comparison group (cyclists presenting to casualty with non-head injuries). McDermott concluded that approved helmets reduce head and face injuries. Thomas concluded that helmets reduce the risk for head and brain injury. The Thomas study included child cyclists only and included regression analysis with adjustment for confounding factors. Maimaris confirmed the protective effect of bicycle helmets for head injuries.

Despite the strong evidence for helmets in the previous work by the Seattle based Thompson group, and the corroboration by the two Australian studies (McDermott and Thomas) and the UK study (Marmaris), the Thompson group conducted a second, larger case-control study approximately five years later. It is of note that, during this time, the use of helmets in the Seattle area increased substantially. They report separately on head and brain injury (Thompson, Rivara et al, 1996), facial injury (Thompson, Nunn et al, 1996) and serious injury (Rivara et al, 1997). The major motivation for the new study was to have sufficient numbers to determine whether the protective effects were consistent across age groups, different helmet types and crash severity, in particular, in crashes with motor vehicles. Their results confirmed each of these hypotheses. They also re-affirmed that helmets provide substantial protection for the upper and mid face, but not the lower face.

The two other US studies are based on data from an emergency department in Arizona by Spaite et al (1991) and from a regional pediatric trauma centre in Western New York by Shafi et al (1998). The Spaite study only included crashes with motor vehicles. In the other studies the percentage of collisions with motor vehicles range from 7% to 30%. He found that helmet wearers were less likely to sustain severe head injury, but, unlike the other studies, also found that helmet wearers were also less likely to sustain severe injuries in general. He concluded that this might indicate that helmet wearers tend to be involved in less severe crashes. Although Shafi’s results were mixed, showing higher head injury overall and higher concussion, but fewer skull fractures and less intra-cranial injury for children, he nonetheless endorses the use of helmets.

The two studies from Canada were based on child cyclists presenting to casualty (Finvers et al, 1996) or admitted to a trauma centre (Linn et al, 1998). Both concluded that helmets provide a protective effect for head injuries.

The most recent Australian study located was a descriptive study by Jacobsen et al (1998) which was based on over 200 bicycle-related injury presentations (with helmet status information) at a Tasmanian hospital. The data support a protective effect of helmets with respect to head injury and the authors conclude that helmet use should be encouraged for both on and off road riding.

Outcomes

With the exception of the Thompson series, most studies used different systems for classifying injury location and injury severity. In articles where head and brain injury were not defined, but could be constructed, the definitions used by Thompson et al (1989), were used to differentiate between head injury and brain injury. The Thompson head injury definition corresponds to all injuries to the parts of the head expected to be covered by a helmet and the brain injury definition corresponds to concussion or more serious brain dysfunction. Exceptions to this are noted in Table 3.

Although the original protocol included only head, brain and facial injury, several studies also included information on neck and fatal injuries (Table 2), so separate analyses were conducted on each of these five outcomes.

Head injury

Efficacy odds ratios for head injury were computed from data extracted from 13 studies (Table 3, Figure 1). All but one of these showed a large protective effect (OR 0.0 to 0.6). The most recent study (Shafi et al, 1998) was the only one with a higher rate of head injury among the subjects (children) wearing helmets compared with the non-helmet group (68% vs 60% OR=1.37). This difference was not statistically significant. This study appears to differ from the others in the high head injury rate among both helmet wearers (68%) and non-wearers (60%). This may be due to hospital admission being an inclusion criterion for this study and the seriousness of injury for cases presenting for admission for that particular hospital (a regional pediatric trauma centre).

Slightly different definitions of head as a body region were employed in the various studies (Table 3). Some studies distinguish only head, upper extremity, lower extremity and trunk and therefore include facial injuries with head injuries. Also, some studies include minor as well as major injury. All studies except one include both skull fractures and brain injury. In Wasserman & Buccini (1990), results are presented separately for skull fractures and concussion and it can’t be determined how many participants sustained both injury types. For this reason, this study is excluded from the meta-analysis of head injury.

There is significant heterogeneity across the efficacy estimates of the 12 studies (Q=52 on 11 df, p<0.001). The random effects estimate of the summary odds ratio for head injury is 0.40 with 95% confidence interval (0.29, 0.55). Thus, it is estimated that helmets reduce the risk of head injury by 60%.

Brain injury

Brain injury is a subset of head injury generally including concussion with or without more severe intracranial injury. Efficacy odds ratios for brain injury were computed from data extracted from 8 studies (Table 3, Figure 1). The definition of concussion varies (some studies only include loss of consciousness). All but one of the studies showed a large protective effect (OR 0.0 to 0.6), though not all results were individually statistically significant. As observed for head injury, Shafi et al (1998) was the study with a higher rate of brain injury among the children wearing helmets compared with the non-helmet group (68% vs 54% OR=1.77). This difference is not statistically significant.

Table 3. Individual and combined helmet efficacy estimates for head, brain, facial, neck and fatal injury

INJURY OUTCOME	Cases		Controls		Outcome %		OR (95% CI)	Outcome	
Study details	H	NH	H	NH	H	NH	H vs NH	Defn	Sev.
HEAD INJURY									
Dorsch et al 87	62	61	60	14	51%	81%	0.24(0.12, 0.47)	- face	-+
Wasserman et al 88	0	7	8	6	0%	54%	0.00(0.00, 0.81)*	+face	-+
Thompson et al 89	17	218	103	330	14%	40%	0.25(0.15, 0.43)	h	-+
Wasserman & Buccini 90	1	9	108	73	1%	11%	0.08(0.01, 0.61)	skull	+
Spaite et al 91	1	37	115	131	1%	22%	0.03(0.00, 0.23)	- face	+
McDermott et al 93	90	468	276	876	25%	35%	0.61(0.47, 0.79)	- face	-+
Maimaris et al 94	4	100	110	828	4%	11%	0.30(0.11, 0.83)	- face	+
Thomas et al 94	31	67	126	140	20%	32%	0.51(0.32, 0.84)	h	-+
Finvers et al 96	4	72	92	531	4%	12%	0.32(0.11, 0.90)	+face	+
Thompson, Rivara et al 96	222	535	1496	1137	13%	32%	0.32(0.26, 0.38)	h	-+
Jacobson et al 98	18	38	97	76	16%	33%	0.37(0.20, 0.70)	+face	-+
Linn et al 98	101	467	226	668	31%	41%	0.64(0.49, 0.83)	+face	-+
Shafi et al 98	21	107	10	70	68%	60%	1.37(0.61, 3.09)	- face	+
Combined head estimate (excluding Wasserman & Buccini 90)							0.40(0.29, 0.55)		
BRAIN INJURY									
Dorsch et al 87	36	34	86	41	30%	45%	0.50(0.28, 0.92)	C/I	-+
Wasserman et al 88	0	3	8	10	0%	23%	0.00(0.00, 3.88)*	C	?
Thompson et al 89	4	95	103	330	4%	22%	0.13(0.05, 0.38)	C/I	+
Wasserman & Buccini 90	32	34	77	48	29%	41%	0.59(0.32, 1.07)	C	?
Thomas et al 94	8	31	126	140	6%	18%	0.29(0.13, 0.65)	C/I	+
Thompson, Rivara et al 96	62	141	1496	1137	4%	11%	0.33(0.25, 0.45)	C/I	+
Linn et al 98	5	57	322	1078	2%	5%	0.29(0.12, 0.74)	C	?
Shafi et al 98	21	96	10	81	68%	54%	1.77(0.79, 3.98)	C/I	+
Combined brain estimate							0.42(0.26, 0.67)		
FACIAL INJURY									
Dorsch et al 87	1	7	121	68	1%	9%	0.08(0.01, 0.67)	AIS	+
Thompson et al 90	30	182	83	236	27%	44%	0.47(0.30, 0.74)	nh	-+
Wasserman & Buccini 90	2	3	107	79	2%	4%	0.49(0.08, 3.02)	?	+
McDermott et al 93	94	464	272	880	26%	35%	0.66(0.51, 0.85)	AIS	-+
Maimaris et al 94	22	212	92	716	19%	23%	0.81(0.49, 1.32)	FN	+
Thompson, Nunn et al 96	73	133	1133	846	6%	14%	0.41(0.30, 0.55)	UF	+
Thompson, Nunn et al 96	52	89	1133	846	4%	10%	0.44(0.31, 0.62)	MF	+
Thompson, Nunn et al 96	297	264	1133	846	21%	24%	0.84(0.70, 1.01)	LF	+
Combined facial estimate (excluding Thompson, Nunn 96 (MF LF))							0.53(0.39, 0.73)		
NECK INJURY									
Wasserman & Buccini 90	14	6	95	76	13%	7%	1.87(0.68, 5.09)	sr	
McDermott et al 93	21	44	345	1300	6%	3%	1.80(1.06, 3.07)	AIS	
Rivara et al 97	48	43	1666	1627	3%	3%	1.09(0.72, 1.65)	AIS	
Combined neck estimate							1.36(1.00, 1.86)		
FATAL INJURY									
Thompson et al 89	0	3	120	545	0.0%	0.5%	0.00(0.0, 11.09)*		
Spaite et al 91	1	10	115	158	0.9%	6.0%	0.14(0.0, 0.99)*		
McDermott et al 93	2	12	364	1332	0.5%	0.9%	0.61(0.07, 2.76)*		
Maimaris et al 94	0	2	114	926	0.0%	0.2%	0.00(0.0, 43.48)*		
Rivara et al 97	1	13	1717	1659	0.1%	0.8%	0.07(0.002,0.50)*		
Shafi et al 98	0	3	31	174	0.0%	1.7%	0.00(0.0, 14.04)*		
Combined fatality estimate							0.27(0.10, 0.71)		

Study subjects: H=subjects wearing a helmet; NH=subjects not wearing a helmet

* Exact confidence interval

Head injury: - face excludes face; + face includes face; h=regions covered by helmet, skull=skull fractures only

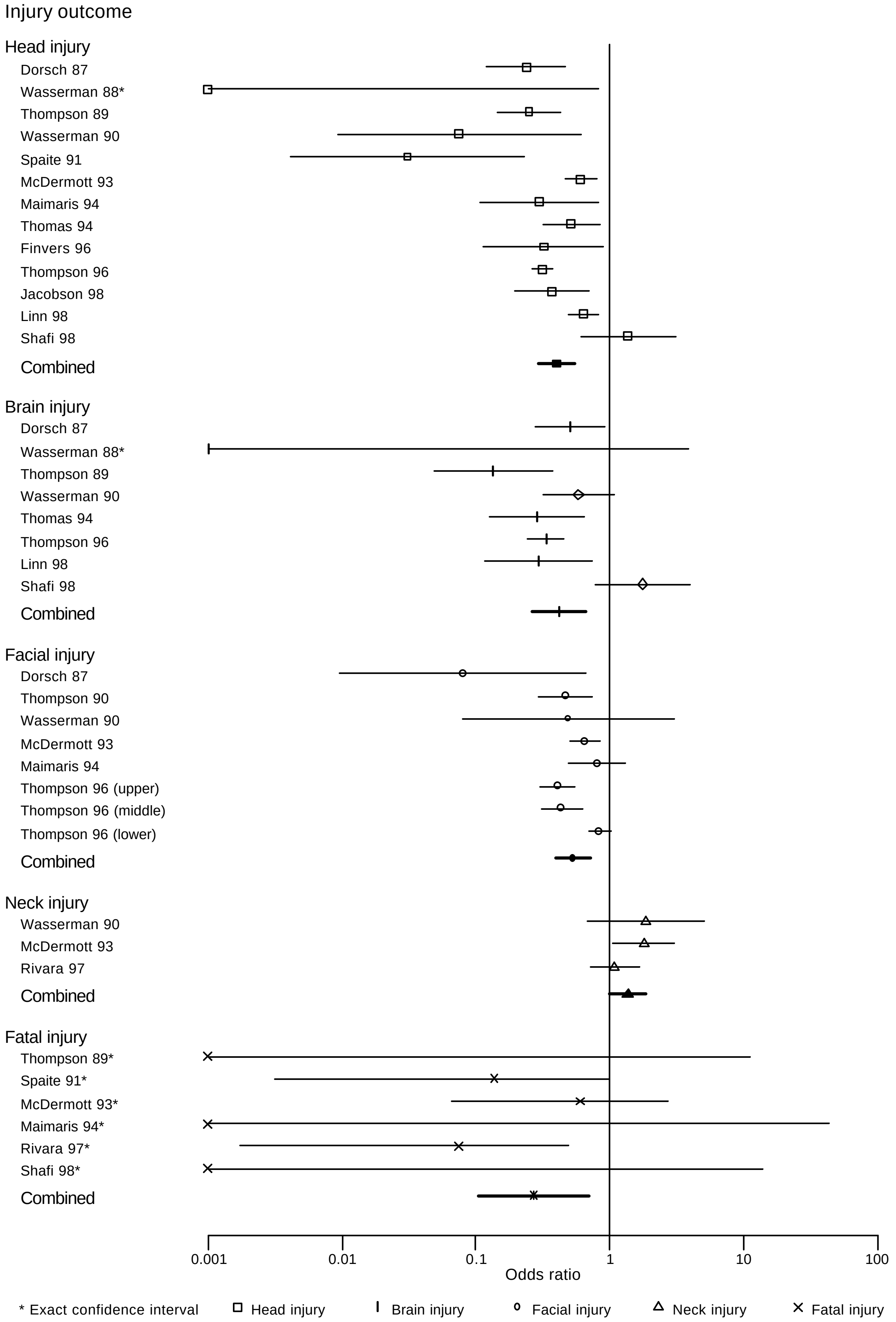
Brain injury: C=concussion; C/I=concussion and/or intracranial injury

Facial injury: AIS=AIS defn of face; nh=non-helmet (eyebrows to chin); FN=face or neck; UF=upper face; MF=mid face; LF=lower face

Neck injury: sr=self report, AIS=AIS definition of neck

Injury severity: - =(head) lacerations; += (brain) loss of consciousness; ?=not specified

Figure 1. Individual study and combined odds ratios (95% confidence interval) for head, brain, facial, neck and fatal injury for helmeted vs unhelemeted cyclists involved in crashes



There is significant heterogeneity across the efficacy estimates for the 8 studies (Q=22 on 7 df, p=0.002). The random effects estimate of the summary odds ratio for brain injury is 0.42 with 95% confidence interval (0.26, 0.67).

Facial injury

Six studies provided estimates of helmet efficacy for facial injury (Table 3, Figure 1). All odds ratios are less than one, but not all are statistically significant. A synthesis of these results is difficult due to differing definitions of facial region, severity of injury and the control group. One study includes facial and neck injury as a combined group (Maimaris et al, 1994). Some studies include minor injury. Thompson et al (1990 and 1996) exclude cyclists with head injury from the control group. Their latter study (1996) provides three separate estimates for the upper, mid and lower face providing strong evidence for a decreasing protective effect from the helmet rim. Combining the Thompson (1996) result for the upper face with results from the other five studies results in a statistically significant heterogeneity test (Q=11 on 5 df, p=0.04). The random effects estimate of the summary odds ratio for facial injury is 0.53 with 95% confidence interval (0.39, 0.73). If the more conservative estimate for lower facial injury of Thompson (1996) is used instead of the estimate for the upper face, the result is still statistically significant (0.67 with 95% confidence interval (0.51, 0.87)).

Neck injury

There were only three studies with sufficient injury details to compute an efficacy estimate for neck injury (Table 3, Figure 1). The information was based on self-report for Wasserman & Buccini (1990) and AIS coding in McDermott et al (1993) and Rivara et al (1997). All showed a greater incidence of neck injury among the helmet wearers, but the odds ratio estimated by Rivara was reduced to less than one on adjustment for age. The combined estimate was not strictly statistically significant 1.36 (1.00, 1.86). This is the fixed effects estimate since there was no strong evidence for heterogeneity (Q= 2.5 on 2 df, p=0.3).

Fatal injury

Six studies reported results of fatal injury (Table 3, Figure 1). In each of these studies, the percentage of fatally injured cyclists among those wearing helmets was less than the percentage of fatally injured cyclists among those not wearing helmets. The difference was statistically significant in two of the studies (Spaite et al 1991 and Rivara et al 1997). The percentages were low in all studies. In three of the studies, no fatalities were observed among helmeted cyclists. The combined estimate for the odds ratio for fatal injury for helmet wearers vs non-helmet wearers was also statistically significant 0.27 with 95% confidence interval (0.10, 0.71). This is the fixed effects estimate since there was no evidence for heterogeneity (Q=3.5 on 5 df, p=0.6).

4. Discussion

This formal summarisation of studies of individual cyclists in various settings has confirmed the clear benefits of helmets in terms of injury risk. The upper bounds of the 95% confidence intervals provide conservative risk reduction estimates of at least 45% for head injury, 33% for brain injury, 27% for facial injury and 29% for fatal injury.

The issue of publication bias must be considered in the assessment of any meta-analysis of published studies, especially when the majority of studies that qualified for inclusion contained statistically significant results. The funnel plots in Figure 2 indicate a small degree of publication bias may be operating for head injury, but not brain injury. The most marked deviation is for facial injury, but the number of studies is small. There aren't enough neck injury results for adequate assessment and there is no evidence of distortion for fatal injury.

Despite these patterns the strength of the associations are compelling. A basic sensitivity analysis indicated that at least 11 large non-significant negative studies[1] would be required to totally counteract results for head injury (2 for facial injury). The fact that the literature search produced articles that did not endorse helmets (7 out of 63 distributed across several journals) provides some evidence against the likelihood that negative studies, if submitted, were rejected for publication. Some of the arguments against helmets centred on conflicting interpretations of results from population studies in which time trends in rates of head injury and non-head injury among hospitalised cyclists were compared with trends in rates of helmet use in the corresponding region. Population (or ecological) studies provide the weakest form of epidemiological evidence for associations (Rothman, 1986). However, Povey et al (1999) provide convincing support for the link between helmets and the prevention of head injury in their population study of national data from New Zealand in the period 1990-1996.

The quantification of risk reduction was our primary justification for using individually based studies. However, the validity of the final risk summary is contingent on the validity and combinability of the individual risk estimates. There are several sources of possible bias that may be operating. Indeed, the heterogeneity of results detected is not surprising given the many different crash settings, helmet types, injury definitions and types of cyclists. Our analysis was based on crude unadjusted odds ratios. Many of the larger studies also presented results adjusting for potential confounders such as age and crash severity (through motor vehicle involvement or severity of other injuries) (eg Dorsch et al, 1987; Thompson et al, 1989; Maimaris et al, 1994; Thomas et al, 1994; and Thompson, Nunn et al, 1996). In all of these studies, the results were essentially unchanged after adjustment. So it is unlikely that our summary results have been affected to any large extent by confounding by these factors.

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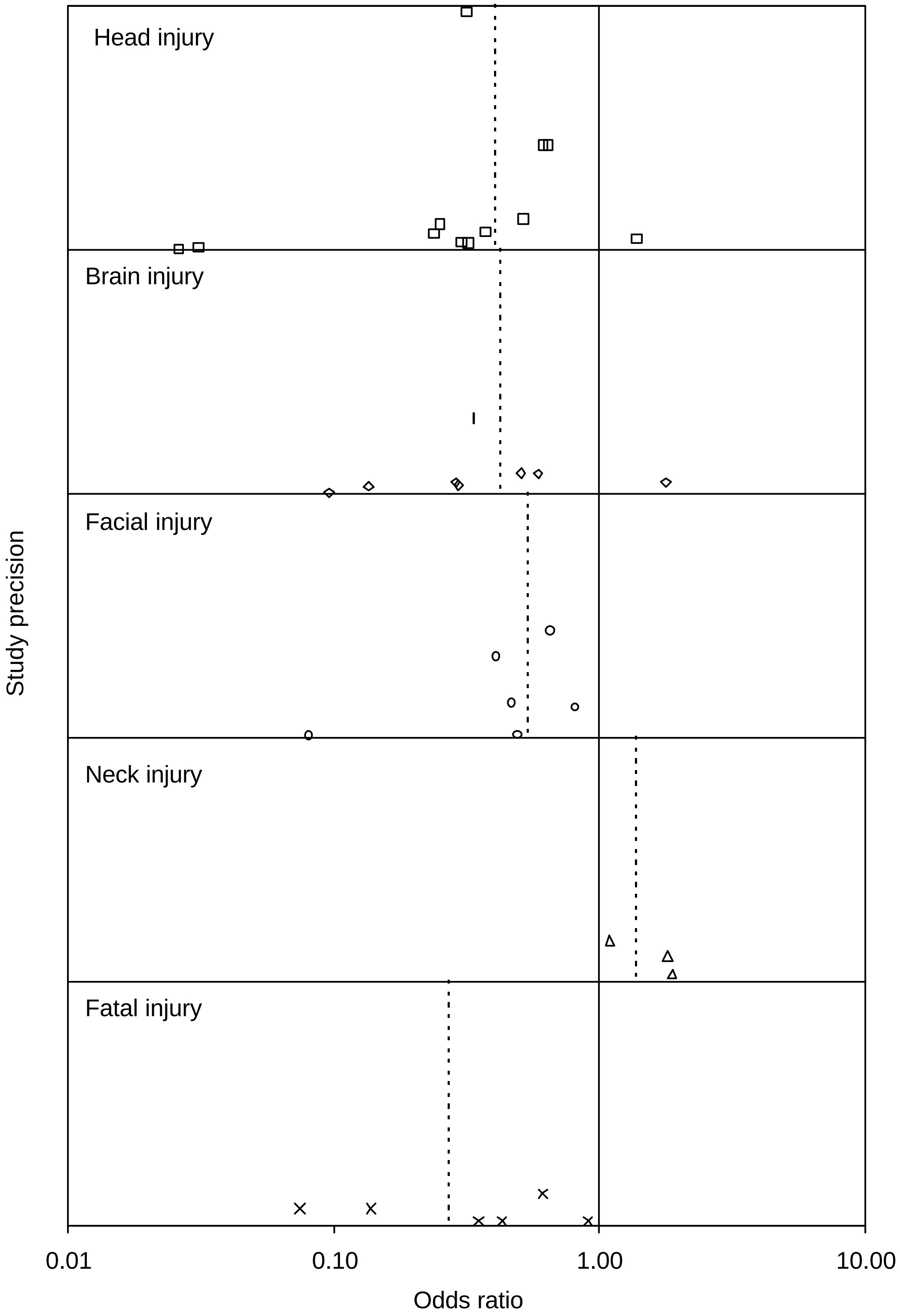
[1] Size 500 OR 1.35

Figure 2. Funnel plots for bicycle helmet efficacy for head, brain, facial, neck and fatal injury (Dashed lines indicate summary odds ratios.)



The use of hospital controls (ie cyclists presenting to emergency departments with non-head injuries) may be another possible source of bias. On the one hand, this could underestimate the effect by excluding helmeted cyclists who crashed and did not require medical care. On the other hand, it could overestimate the effect, if the likelihood of seeking medical care was associated with helmet use (ie if a helmeted rider was more likely to seek treatment for non-head injuries). The data extracted from Thompson et al (1989) and Thompson et al (1990) are based on hospital controls, but they also report similar results using a separate group of population controls (cyclists who crashed, but did not necessarily seek treatment) in these papers. Apart from the additional cost of locating an appropriate group of population controls, the main disadvantage is the possibility of reporting bias. However, after additional analysis by both Dorsch et al (1987) and Thompson et al (1989), neither concluded that systematic bias affected their results.

Another possible confounding factor is risk-taking behaviour. Spaite et al (1991) looked at the incidence of non-head injuries as a marker for risk taking and concluded that helmet wearers were more cautious due to their lower incidence of non-head injury. On the other hand, McDermott et al (1993) found non-head injuries were more common and more severe among helmeted riders and thus concluded that the protective effects were not a result of safer riding behaviour on the part of the helmet wearers.

There was some evidence for an increased risk for neck injury in helmeted riders. Only three studies provided details for these injuries. It is hypothesised that the result may be influenced by the types of helmets worn. The odds ratios are largest for the two earlier studies (Wasserman & Buccini, 1990 and McDermott et al, 1993) with data collection prior to 1990 when there was a higher proportion of heavier, hard shell helmets worn. The third study is based on data from the early 1990s with a risk estimate closer to one (OR=1.09) (Rivara et al, 1997). This result may warrant further research to ensure that helmet design does not increase the likelihood of neck injury to the wearer.

Overall, these results provide clear evidence for the benefit of wearing helmets while cycling, in terms of risk reduction for not only head and brain injury, but also facial injury and fatal injury. These results are applicable to riders of all ages, both in less severe crashes and in collisions with motor vehicles. These results confirm those published in initial studies in Australia and the USA over a decade ago, although the more recent studies are confined to these two countries, Canada and the United Kingdom.

Furthermore, there should be a clear distinction between the benefits of helmets per se and the benefits of compulsory helmet wearing laws. Some of the opponents of compulsory helmet wearing laws have chosen to include the safety benefits of helmets within their criticism of cycle helmet wearing laws. As this paper demonstrates, there is clear evidence of the safety benefits of cycle helmets with respect to head, brain and fatal injuries. Any reasonable objection to compulsory helmet wearing laws can only be based on issues other than the efficacy of helmets themselves. For example, there is a civil rights aspect to any legislation that seeks to restrict the behaviour of citizens and debate over such issues is a healthy aspect of modern democracy. This is, however, a political or ethical debate, not a scientific one.

The issue for future action is not the benefits of cycle helmets per se, for this has been established repeatedly in the past and confirmed here, but how best to encourage the use of cycle helmets by all riders.

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Appendix A. Statistical details

Definition of odds ratio for a single study
An odds ratio (OR) measuring the efficacy of helmets in preventing injury is defined as the odds for head injury for helmeted cyclists divided by the odds for head injury for unhelmeted cyclists. If *a* is the number of helmeted cyclists sustaining head injury and *b* is the number of helmeted riders not sustaining head injury, the odds for head injury for helmeted riders is defined as *a/b*, since the odds is the probability of sustaining head injury (estimated by *a/(a+b)*) divided by the probability of not sustaining head injury (estimated by *b/(a+b)*). Analogously, the odds for head injury for unhelmeted riders is *c/d*. The ratio of these two quantities gives the odds ratio for helmeted versus unhelmeted riders. This is the cross product (ad/bc).

	Head injury	No head injury	Total
Helmet	a	b	a+b
No helmet	c	d	c+d

OR (helmet vs no helmet) = (a/b)/(c/d) = ad/bc

Definition of a 95% confidence interval for a single study
The odds ratio gives a point estimate of the efficacy of helmets. In order to draw inference about efficacy for a single study, it is necessary to obtain information on the variation associated with this estimate. The standard procedure is to compute a 95% confidence interval for the efficacy parameter based on the estimate of the standard error of the estimate. In the case of the odds ratio it is usual to obtain an approximate confidence interval by first computing the approximate standard error of the log of the odds ratio and then converting the confidence interval on the log scale back into the original scale.

$$SE(\ln OR) \cong \sqrt{[1/a + 1/b + 1/c + 1/d]}$$

$$95\% \text{ CI for } OR = \exp(\ln OR \pm 1.96 * SE(\ln OR))$$

These formulae are appropriate when the numbers of subjects in each cell of the 2x2 table (a, b, c and d) are not too small. Exact confidence intervals were computed in the case of zero cells and 0.25 was added to each cell in these cases, prior to the meta-analysis.

Meta-analysis techniques
The DerSimmonian-Laird method (DerSimmonian & Laird, 1986), implemented in STATA Version 5.0 (StataCorp, 1997 and Sharp & Stern, 1998) was used to obtain a summary odds ratio and a 95% confidence interval for injury for helmet wearers versus non-wearers across the number of studies. There are two main methods of combination across studies, referred to as fixed effects and random effects models. Random effects is the preferred model in the presence of significant heterogeneity across studies. If, on the other hand, the point estimates for the odds ratios are reasonably similar, the fixed effects model suffices. The results of the two models are generally similar if there is not marked heterogeneity across the individual studies. In this analysis, the random effects estimate was quoted if a formal chi-square test of heterogeneity across studies was statistically significant (based on $p < 0.05$). The confidence intervals obtained from the random effects model are generally wider (and thus more conservative) than those obtained using the fixed effect model, since extra variance is added due to the between study variability.

Appendix B. Article summaries

Author	Dorsch et al
Title	Do bicycle safety helmets reduce severity of head injury in real crashes?
Year	1987
Journal	Accident Analysis & Prevention
Country	Australia
Design	Self reported retrospective questionnaire of crash and helmet use
Outcome	Presence and severity and type of head injury Brain injury, skull fracture, soft tissue injury, facial fracture
Subjects	197 members of registered bicycling clubs reporting a bicycle crash in the past 5 years & receiving an impact to the head or helmet
Helmet use	62% reported wearing a helmet at the time of the impact
Helmet type	56% hairnet (racing style) 30% poor hard shell (soft/no liner) 13% good hard shell (stiff liner)
Results	Association between helmet use and reduced severity of injury (both unadjusted and adjusted) The protective effect of helmets persisted even when the severity of the crash was taken into account.
Comments	Self reported injury and helmet status, with 67% response rate. Injuries coded according to AIS body regions and severity Mean age 29 (SD 15)
Extracted	

	Case		Control		
	H	NH	H	NH	Crude OR (CI)
HI1+	62	61	60	14	0.24 (0.12, 0.47)
HI2+	34	31	88	44	0.55 (0.30, 1.01)
HF	2	3	120	72	0.40 (0.07, 2.45)
FI	1	7	121	68	0.08 (0.01, 0.67)
BI	36	34	86	41	0.50 (0.28, 0.92)

HI1+ = Any head injury (AIS severity 1-5)
HI2+ = Any head injury (AIS severity 2-5) (ie excluding least severe injury)
HF = Skull fractures
FI = Facial fractures
BI Brain injury (AIS body region but severity unclear: appears to be concussion with or without loss of consciousness)

Conclusion	Helmets reduce severity of head injury

<table>
<tr><td>Author</td><td colspan="6">Wasserman et al</td></tr>
<tr><td>Title</td><td colspan="6">Bicyclists, helmets and head injuries: a rider-based study of helmet use and effectiveness</td></tr>
<tr><td>Year</td><td colspan="6">1988</td></tr>
<tr><td>Journal</td><td colspan="6">American Journal of Public Health</td></tr>
<tr><td>Country</td><td colspan="6">US</td></tr>
<tr><td>Design</td><td colspan="6">Bicyclists interviewed at roadside</td></tr>
<tr><td>Outcome</td><td colspan="6">Helmet wearing rates
Head injury in past 18 months</td></tr>
<tr><td>Subjects</td><td colspan="6">516 bicyclists (aged >10yrs) interviewed at roadside Jul-Aug 1984 during the day in urban Vermont</td></tr>
<tr><td>Helmet use</td><td colspan="6">8% wearing helmets at time of interview
19% owned helmets</td></tr>
<tr><td>Helmet type</td><td colspan="6">All helmets had hard shells and energy absorbing liners which met or exceeded ANSI standards</td></tr>
<tr><td>Results</td><td colspan="6">Wearing rates higher for married, those with more education, those who reported higher susceptibility to & greater seriousness of head injury
Only 4% (21 subjects) reported a crash in which they struck their head (in last 18 m)
OR for head injury(no helmets vs helmets) = 19.6 (1.2, 331)</td></tr>
<tr><td>Comments</td><td colspan="6">76% response rate
Mean age 23 years
58% students
Authors got their estimate of OR by adding 0.5 to each cell and used Miettinen method for 95%CI; Exact CI is (1.2, ∞)
Authors comment that study is small & relied on the interview for documentation of head injury and helmet use</td></tr>
<tr><td>Extracted</td><td></td><td colspan="2">Case</td><td colspan="2">Control</td><td>Crude OR (CI)</td></tr>
<tr><td></td><td></td><td>H</td><td>NH</td><td>H</td><td>NH</td><td></td></tr>
<tr><td></td><td>HI</td><td>0</td><td>7</td><td>8</td><td>6</td><td>0.00 (0.00, 0.81) (Exact CI)</td></tr>
<tr><td></td><td>C</td><td>0</td><td>3</td><td>8</td><td>10</td><td>0.00 (0.00, 3.88) (Exact CI)</td></tr>
<tr><td></td><td colspan="6">HI = concussion or lacerations requiring sutures
C = concussion</td></tr>
<tr><td>Conclusion</td><td colspan="6">Bicyclists wearing helmets less likely to have sustained head injuries</td></tr>
</table>

Author	Thompson et al
Title	A case-control study of the effectiveness of bicycle safety helmets
Year	1989
Journal	New England Journal of Medicine
Country	US
Design	Case-control study
Outcome	Head injury HI including forehead, scalp, ears, skull, brain, brain stem (those areas of the head expected to be protected by a helmet) Brain injury BI including concussion or more serious brain dysfunction (AIS 2+)
Subjects	Bicyclists treated at A&E in Seattle 12 months 1986-87 (includes deaths) Cases = 235 HI, 99 BI Controls A) 433 emergency room controls = sustaining injury, but not to head B) 558 population controls = cyclists who crashed
Helmet use	Cases with HI 7% Cases with BI 4% Emergency room controls 24% Population controls 23%
Results	After controlling for age, sex, income, education, cycling experience and the severity of the accident, riders with helmets had an 85% reduction in risk of head injury; 88% reduction in risk of brain injury
Comments	Questionnaire response rate 86% 61% of cases aged <15

Extracted

	Case		Controls (A)			
	H	NH	H	NH	Crude OR (CI)	Adjusted* OR (CI)
HI	17	218	103	330	0.25 (0.15, 0.43)	0.26 (0.14, 0.49)
BI	4	95	103	330	0.13 (0.05, 0.38)	0.19 (0.06, 0.57)
Death	0	3	120	545	0.35 (0.01, 20.5)	0.00 (0.00, 11.09)(exact)

*Adjusted for age, sex, income, education, cycling, crash severity, hospital

	Case		Controls (B)			
	H	NH	H	NH	Crude OR (CI)	Adjusted* OR (CI)
HI	17	218	130	428	0.26 (0.15, 0.44)	0.15 (0.07, 0.29)
BI	4	95	130	428	0.14 (0.05, 0.38)	0.12 (0.04, 0.40)

*Adjusted for age, sex, income, education, cycling, crash severity

Conclusion	Bicycle helmets are highly effective in preventing head injury and particularly important for children.

<table>
<tr><td>Author</td><td>Thompson et al</td></tr>
<tr><td>Title</td><td>A case control study of the effectiveness of bicycle safety helmets in preventing facial injury</td></tr>
<tr><td>Year</td><td>1990</td></tr>
<tr><td>Journal</td><td>American Journal of Public Health</td></tr>
<tr><td>Country</td><td>US</td></tr>
<tr><td>Design</td><td>Case-control study</td></tr>
<tr><td>Outcome</td><td>Facial injury FI (injury to eyebrows, chin, mouth & teeth)
Serious facial injury SFI (lacerations, fractures to eyebrows, chin, mouth & teeth)
Serious upper facial injuries SUFI (midface, nose, eye/orbit)</td></tr>
<tr><td>Subjects</td><td>Bicyclists treated at A&E in Seattle 12 months 1986-87 (includes deaths)
Cases = 212 FI, 127 SFI , 44 SUFI
Controls
A. 319 emergency room controls = sustaining injury, but none to face/head
B. 558 population controls = cyclists who crashed</td></tr>
<tr><td>Helmet use</td><td>Cases with FI 14%
Cases with SFI 16%
Cases with SUFI 9%
Emergency room controls 26%</td></tr>
<tr><td>Helmet type</td><td>90% of helmets hard shell</td></tr>
<tr><td>Results</td><td>Results not statistically significant for FI 0.69 with emergency room controls after adjustment for age (Results just significant using population controls OR=0.5(0.3,0.9)
Results not statistically significant for SFI 0.81 after adjustment for age
Positive results for SUFI (OR 0.27 emergency controls and 0.14 for population controls).</td></tr>
<tr><td>Comments</td><td>Questionnaire response rate 85%
Data collected as part of case-control study of head injury (Thompson et al 1989)
Authors comment that additional adjustment for sex, cycling experience, severity, education, income and hospital had no effect
Cyclists with head injury excluded from the control group (since helmet use associated with head injury)
Authors recommend using results for SFI only since the ascertainment of FI increased by head injury and linked to helmet use.
Authors suggest that association between helmet use and SUFI linked to
1. protective effect of helmets
2. association between SUFI and head injury</td></tr>
<tr><td>Extracted</td><td>
<table>
<tr><td></td><td>Case</td><td></td><td>Controls (A)</td><td></td><td></td><td></td></tr>
<tr><td></td><td>H</td><td>NH</td><td>H</td><td>NH</td><td>Crude OR (CI)</td><td>Adjusted* OR (CI)</td></tr>
<tr><td>FI</td><td>30</td><td>182</td><td>83</td><td>236</td><td>0.47 (0.30, 0.74)</td><td>0.69 (0.41, 1.1)</td></tr>
<tr><td>SFI</td><td>21</td><td>106</td><td>83</td><td>236</td><td>0.56 (0.33, 0.96)</td><td>0.81 (0.45, 1.5)</td></tr>
<tr><td>SUFI</td><td>4</td><td>40</td><td>83</td><td>236</td><td>0.28 (0.10, 0.82)</td><td>0.27 (0.1, 0.8)</td></tr>
</table>
*Adjusted for age</td></tr>
<tr><td>Conclusion</td><td>Bicycle helmets have some protective effect against serious upper facial injuries</td></tr>
</table>

Author	Wasserman & Buccini
Title	Helmet protection from head injuries among recreational bicyclists
Year	1990
Journal	American Journal of Sports Medicine
Country	US
Design	Questionnaire survey
Outcome	Self reported injuries by location
Subjects	191 readers of US bicycle magazines who responded that they had had a cycle accident in the past 5 years (1980-85) where they had struck their head
Helmet use	57% wearing ANSI approved helmets
Helmet type	100% ANSI approved helmets
Results	Helmet wearers were significantly older than those not wearing helmets. Helmet wearers and non-wearers reported similar numbers of injuries below the neck Helmet wearers reported significantly fewer skull fractures & facial soft tissue injuries Helmet wearers reported more neck injuries (but not stat significant)
Comments	Self report questionnaire; authors discuss shortcomings briefly (recall bias and injury severity bias – but not response bias) Mainly adults: only 8% under 20 23% of crashes involved motor vehicles 50% sought medical treatment 26% admitted to hospital No combined data on head injuries (skull fractures and concussion reported separately) Design similar to Dorsch et al 1987 Australian study, but no AIS coding of self-reported injuries

Extracted		Case		Control			
		H	NH	H	NH	Crude OR (CI)	Exact
	SF	1	9	108	73	0.08 (0.01, 0.61)	(0.002, 0.57)
	FF	2	3	107	79	0.49 (0.08, 3.02)	(0.04, 4.42)
	C	32	34	77	48	0.59 (0.32, 1.07)	
	NI	14	6	95	76	1.87 (0.68, 5.09)	

SF = skull fractures
FF = facial fractures
C = concussion
NI =neck injury

Conclusion	Bicycle helmets are effective in preventing head injuries

<table>
<tr><td>Author</td><td colspan="7">Spaite et al</td></tr>
<tr><td>Title</td><td colspan="7">A prospective analysis of injury severity among helmeted and non-helmeted bicyclists involved in collisions with motor vehicles</td></tr>
<tr><td>Year</td><td colspan="7">1991</td></tr>
<tr><td>Journal</td><td colspan="7">Journal of Trauma</td></tr>
<tr><td>Country</td><td colspan="7">US</td></tr>
<tr><td>Design</td><td colspan="7">Prospective study of injury severity to head and other body regions in relation to helmet use</td></tr>
<tr><td>Outcome</td><td colspan="7">Location and types of major injury
Injury Severity Score (ISS)
Proportion with ISS > 15</td></tr>
<tr><td>Subjects</td><td colspan="7">284 bicyclists involved in collisions with motor vehicles seen at a level-I trauma centre 1986-89</td></tr>
<tr><td>Helmet use</td><td colspan="7">41% wore helmets</td></tr>
<tr><td>Helmet type</td><td colspan="7">Not specified</td></tr>
<tr><td>Results</td><td colspan="7">Helmet users had lower incidence of major head injury than non-users (1% vs 22%)
Helmet users less severely injured than non-users (5% vs 47% with high ISS and mean ISS score 4 vs 18)
Helmet users without HI were also less severely injured than non-users without HI (4% vs 32% and mean ISS 4 vs 13)
Children were more severely injury
Mortality was significantly higher for non-helmet users than users
Helmet use was highest for adults, females</td></tr>
<tr><td>Comments</td><td colspan="7">Mean age 23.
All crashes involved motor vehicles.
11 fatalities included</td></tr>
<tr><td>Extracted</td><td></td><td colspan="2">Case</td><td colspan="2">Control</td><td></td><td></td></tr>
<tr><td></td><td></td><td>H</td><td>NH</td><td>H</td><td>NH</td><td>Crude OR (CI)</td><td>Exact CI</td></tr>
<tr><td></td><td>HI</td><td>1</td><td>37</td><td>115</td><td>131</td><td>0.03 (0.00, 0.23)</td><td>(0.00,0.19)</td></tr>
<tr><td></td><td colspan="7">HI = major head injury (subdural haematoma, epidural haematoma, basilar skull fracture)</td></tr>
<tr><td></td><td>Death</td><td>1</td><td>10</td><td>115</td><td>158</td><td>0.14 (0.02,1.09)</td><td>(0.00,0.99)</td></tr>
<tr><td>Conclusion</td><td colspan="7">Concludes that helmet wearers may be safer riders since helmet users without HI were less severely injured than non-users without HI.</td></tr>
</table>

Author	McDermott et al
Title	The effectiveness of bicyclist helmets: a study of 1710 casualties
Year	1993
Journal	Journal of Trauma
Country	Australia
Design	Compares head and other injuries sustained by bike riders wearing and not wearing helmets
Outcome	Head injury, face injury, neck injury, chest injury, extremity injury, injury severity
Subjects	1710 injured bicyclists presenting at 2 specific hospitals and bicyclists who died at crash scene or before they reached hospital, 1987-89, Melbourne & Geelong
Helmet use	21% wore helmets
Helmet type	Approved (71%) Non-approved (29%)

Results

- Less frequent head injury among approved helmet wearers vs non-wearers
- Less frequent face injury among approved helmet wearers vs non-wearers
- Less severe head injury among approved helmet wearers vs non-wearers
- More frequent non-head injury in helmeted vs unhelmeted
- More frequent neck injury in helmeted vs unhelmeted.

	Appr	Any helmet
HI	.61*	.71*
FI	.72*	.74*
NonHI	1.26*	1.16*
Male HI	.59*	
Fem HI	.69	
<18 HI	.55*	
18+ HI	.75	

- Risk reduction estimates for head injuries of 29% for all helmets, 39% for approved helmets and 45% for approved helmets excluding dislodgments.
- Risk reduction estimate for face injuries of 28% for approved helmets

Comments

Mean age 18 years (SD 12)

30% in collisions with a motor vehicle.

There is a detailed comparison with Thompson et al 1989, whose efficacy estimates (61% reduction) were less conservative than these (30% reduction), even after some adjustments to account for different definitions (Seattle included forehead lacerations as head injuries and excluded death).

There is also important discussion that the estimates are underestimates of true efficacy since the study design excludes helmeted cyclists who sustain a blow to their helmet in a crash, but do not go to hospital if they do not sustain sufficiently severe injury.

The authors use the relative proportion (ie ratio of proportions) and not OR since they say that OR are inappropriate as this is not a case-control study. Thompson 1994 in a letter to the editor states that this study could be usefully analysed as a case-control study (but she makes the statement that the formulae for the crude odds ratio and relative proportion are identical which is not correct). She correctly computes the OR as 0.61, but incorrectly states that it is the same as McDermott's relative proportion, which was, in fact 0.71 (helmet wearers vs unhelmeted). She misread the table and used the relative proportion for approved helmet wearers vs unhelmeted, which is in fact 0.61.

Extracted

	Case		Control			
	H	NH	H	NH	Crude OR (CI)	Exact
HI	90	468	276	876	0.61 (0.47,0.79)	
FI	94	464	272	880	0.66 (0.51,0.85)	
NI	21	44	345	1300	1.80 (1.06, 3.07)	
Death	2	12	364	1332	0.61 (0.14,2.74)	(0.07, 2.76)

HI =injuries to the head defined by AIS body region ie excluding face

FI = injuries to the face defined by AIS body region

NI = injuries to the neck defined by AIS body region

Conclusion

Approved helmets reduce head and face injuries and lessen AIS scores.

<table>
<tr><td>Author</td><td>Maimaris et al</td></tr>
<tr><td>Title</td><td>Injury patterns in cyclists attending an accident and emergency department: a comparison of helmet wearers and non-wearers</td></tr>
<tr><td>Year</td><td>1994</td></tr>
<tr><td>Journal</td><td>British Medical Journal</td></tr>
<tr><td>Country</td><td>UK</td></tr>
<tr><td>Design</td><td>Prospective study of patients with cycle related injuries</td></tr>
<tr><td>Outcome</td><td>Accident type
Nature and distribution of injuries</td></tr>
<tr><td>Subjects</td><td>1042 patients presenting to A&E with cycle related injuries 1992</td></tr>
<tr><td>Helmet use</td><td>11% wore helmets</td></tr>
<tr><td>Helmet type</td><td>Not specified</td></tr>
<tr><td>Results</td><td>No significant differences between helmet wearers and non-helmet wearers in the nature and distribution of injury except for head injuries
Higher wearing rates for children 16% than adults 9%
Higher incidence of head injury in collisions with motor vehicles 18% vs 7%</td></tr>
<tr><td>Comments</td><td>30% aged <16
28% involved in collisions with motor vehicles
Can also extract HI data separately for children <16 and adults.</td></tr>
<tr><td>Extracted</td><td>
<table>
<tr><td></td><td>Case</td><td></td><td>Control</td><td></td><td></td><td></td></tr>
<tr><td></td><td>H</td><td>NH</td><td>H</td><td>NH</td><td>Crude OR (CI)</td><td>Adjusted* OR (CI)</td></tr>
<tr><td>HI</td><td>4</td><td>100</td><td>110</td><td>828</td><td>0.30 (0.11, 0.83)</td><td>0.31 (0.11, 0.86)</td></tr>
<tr><td>F/N</td><td>22</td><td>212</td><td>92</td><td>716</td><td>0.81 (0.49, 1.32)</td><td>0.76 (0.44, 1.30)</td></tr>
<tr><td>Death</td><td>0</td><td>2</td><td>114</td><td>926</td><td>0.00 (0.00, 43.48)</td><td>Exact</td></tr>
</table>
HI includes:
- skull fracture
- brain injury according to computed tomography
- loss of consciousness or amnesia
HI excludes scalp abrasions, lacerations or contusions not associated with loss of consciousness or post-concussion symptoms
F/N Face or neck
* Adjustment for involvement of a motor vehicle</td></tr>
<tr><td>Conclusion</td><td>Confirms protective effect of bicycle helmets.</td></tr>
</table>

<table>
<tr><td>Author</td><td>Thomas et al</td></tr>
<tr><td>Title</td><td>Effectiveness of bicycle helmets in preventing head injury in children: case-control study</td></tr>
<tr><td>Year</td><td>1994</td></tr>
<tr><td>Journal</td><td>British Medical Journal</td></tr>
<tr><td>Country</td><td>Australia</td></tr>
<tr><td>Design</td><td>Case control study by questionnaire completed by children/carers</td></tr>
<tr><td>Outcome</td><td>Upper head injury (UHI)
Loss of consciousness</td></tr>
<tr><td>Subjects</td><td>445 children presenting to 2 Brisbane hospitals with bicycle related injuries 1991-92
Cases 102 children with injuries to upper head
And subset of 41 children who lost consciousness
Controls a) 278 children with injuries other than to the head or face; and
b) 65 children with injuries to the face</td></tr>
<tr><td>Helmet use</td><td>43% wore a helmet at time of the crash</td></tr>
<tr><td>Helmet type</td><td>8% no shell
3% thin shell
78% hard shell
11% not approved</td></tr>
<tr><td>Results</td><td>1. Helmet use less among the UHI cases with
OR 2.0 for upper head injuries for unhelmeted vs helmeted p=0.007 and
OR 2.7(1.5,4.9) adjusting for sex, age, hospital, parental education, cause of accident, contact with a moving vehicle, severity of impact (damage to bike)
2. Helmet use less among ‘loss of consciousness’ cases with
OR 3.4 p=0.002 and
OR 7.3 (2.6, 20.4) adjusted.
3. Wearing a helmet reduced the risk of UHI by 63% & loss of consciousness by 86%.
4. Using face injured controls reduction in UHI risk is 51% (NS)</td></tr>
<tr><td>Comments</td><td>7% had contact with a moving vehicle
Results similar to Thompson et al 89
Authors don’t believe that use of emergency room controls will underestimate risk
Further analysis restricted to children hitting their head or helmet gave same results.
Authors admit that risk-taking behaviour only indirectly controlled for through age, sex, type of accident etc.</td></tr>
<tr><td>Extracted</td><td><table>
<tr><td></td><td>Case</td><td></td><td>Control</td><td></td><td></td><td></td></tr>
<tr><td></td><td>H</td><td>NH</td><td>H</td><td>NH</td><td>Crude OR (CI)</td><td>Adjusted OR (CI)</td></tr>
<tr><td>HI</td><td>31</td><td>67</td><td>126</td><td>140</td><td>0.51 (0.32, 0.84)</td><td>0.37 (0.20, 0.67)</td></tr>
<tr><td>C</td><td>8</td><td>31</td><td>126</td><td>140</td><td>0.29 (0.13, 0.65)</td><td>0.14 (0.05, 0.38)</td></tr>
</table>HI = upper head including the skull, forehead and scalp or loss of consciousness
C = loss of consciousness
Adjusted for sex, age, hospital, parental education, accident cause, bicycle damage</td></tr>
<tr><td>Conclusion</td><td>The risk of head injury is reduced among children wearing a helmet. Current helmet design maximises protection in the type of accident most commonly occurring. Legislation enforcing helmet use among children should be considered.</td></tr>
</table>

<table>
<tr><td>Author</td><td colspan="6">Finvers et al</td></tr>
<tr><td>Title</td><td colspan="6">The effect of bicycling helmets in preventing significant bicycle-related injuries in children</td></tr>
<tr><td>Year</td><td colspan="6">1996</td></tr>
<tr><td>Journal</td><td colspan="6">Clinical Journal of Sport Medicine</td></tr>
<tr><td>Country</td><td colspan="6">Canada</td></tr>
<tr><td>Design</td><td colspan="6">Case-control</td></tr>
<tr><td>Outcome</td><td colspan="6">Serious head injury
Serious injury</td></tr>
<tr><td>Subjects</td><td colspan="6">699 children (3-16 yrs) presenting at ER with bicycle related injuries 1991-93</td></tr>
<tr><td>Helmet use</td><td colspan="6">14% wore helmets</td></tr>
<tr><td>Helmet type</td><td colspan="6">Not specified</td></tr>
<tr><td>Results</td><td colspan="6">The risk of serious head injury was significantly greater when a helmet was not worn OR 3.12 (1.13-8.75).
There was no significant difference in terms of serious injuries overall comparing helmeted and non helmeted children OR 1.11 (0.72-1.72)</td></tr>
<tr><td>Comments</td><td colspan="6">Data included in this study may exclude the most seriously injured patients as seriously injured patients are taken directly to ICU. Exclusion of these patients could have a major impact upon the severity of injury associated with helmet use or non-use.
The 3 authors independently classified injuries as serious or minor.
Fractures included as serious.
Superficial abrasions considered minor
Mean age 9</td></tr>
<tr><td>Extracted</td><td></td><td>Case</td><td></td><td>Control</td><td></td><td></td></tr>
<tr><td></td><td></td><td>H</td><td>NH</td><td>H</td><td>NH</td><td>Crude OR (CI)</td></tr>
<tr><td></td><td>HI</td><td>4</td><td>72</td><td>92</td><td>531</td><td>0.32 (0.12, 0.91)</td></tr>
<tr><td></td><td colspan="6">HI = Concussion, fractures (nose, face, cheek, mouth, skull), haematoma bruising skull, crush injury. Minor injuries excluded (eg superficial abrasions, cuts, lacerations, haematoma)</td></tr>
<tr><td>Conclusion</td><td colspan="6">Helmets provide a protective effect against serious head injury in young children.
Helmet use is not associated with overall reduction in serious injury indicating helmet use is not related to severity of crash.</td></tr>
</table>

<table>
<tr><td>Author</td><td>Thompson, Rivara et al</td></tr>
<tr><td>Title</td><td>Effectiveness of bicycle safety helmets in preventing head injuries. A case control study</td></tr>
<tr><td>Year</td><td>1996</td></tr>
<tr><td>Journal</td><td>Journal of the American Medical Association</td></tr>
<tr><td>Country</td><td>US</td></tr>
<tr><td>Design</td><td>Prospective case control study</td></tr>
<tr><td>Outcome</td><td>Head injury (same definition as Thompson et al 1989 c-c study)
Brain injury (same definition as Thompson et al 1989 c-c study)
Severe brain injury (Intracranial injury or haemorrhage)</td></tr>
<tr><td>Subjects</td><td>757 cases = bicyclists with head injuries (treated or admitted or died) 1992-94
2633 controls = bicyclists treated for non head injury 1992-1994</td></tr>
<tr><td>Helmet use</td><td>29% of cases wore helmets
57% of controls wore helmets
51% overall wore helmets</td></tr>
<tr><td>Helmet type</td><td>49% hard shell
29% thin shell
19% no shell/foam</td></tr>
<tr><td>Results</td><td>
Helmet use is associated with a reduction in the risk of any head injury by 69%; brain injury by 65%; severe brain injury by 74%
No evidence that <6yrs of age need a different type of helmet since no statistically significant difference in effects for different age groups
No difference between effects with respect to motor vehicle involvement
There is a suggestion that hard shell helmets are more protective than no shell helmets for all degrees of head injury; the differences were not statistically significant
</td></tr>
<tr><td>Comments</td><td>Response rate in survey 88%
Authors comment that have underestimated true effect since did not use population based controls
Death figures same as those extracted in Rivara et al 1997 on c-c for facial injuries (same underlying study)</td></tr>
<tr><td>Extracted</td><td><table>
<tr><th></th><th>Case</th><th></th><th>Control</th><th></th><th></th><th></th></tr>
<tr><th></th><th>H</th><th>NH</th><th>H</th><th>NH</th><th>Crude OR(CI)</th><th>Adjusted* OR (CI)</th></tr>
<tr><td>HI</td><td>222</td><td>535</td><td>1496</td><td>1137</td><td>0.32 (0.26-0.38)</td><td>0.31 (0.26-0.37)</td></tr>
<tr><td>BI</td><td>62</td><td>141</td><td>1496</td><td>1137</td><td>0.33 (0.25, 0.45)</td><td>0.35 (0.25, 0.48)</td></tr>
<tr><td>SBI</td><td>15</td><td>47</td><td>1496</td><td>1137</td><td>0.24 (0.13, 0.44)</td><td>0.26 (0.14, 0.48)</td></tr>
<tr><td>Death</td><td>1</td><td>13</td><td>1717</td><td>1659</td><td>0.07 (0.01, 0.57)</td><td>0.07 (0.002, 4961) Exact</td></tr>
</table>
SBI serious brain injury
*Adjustment for age and motor vehicle involvement</td></tr>
<tr><td>Conclusion</td><td>Regardless of type, bike helmets provide protection against HI for cyclists of all ages involved in crashes, including crashes with motor vehicles</td></tr>
</table>

Author	Thompson, Nunn et al
Title	Effectiveness of bicycle safety helmets in preventing serious facial injury
Year	1996
Journal	Journal of the American Medical Association
Country	US
Design	Case control study
Outcome	Facial injuries
Subjects	Patients who sought care for a bicycle related injury at A&E departments 1992-94 Cases 700 cases with serious facial injury – fractures/lacerations – 3 subgroups 206 UF upper facial – forehead, orbit, eyes, ears 141 MF mid facial – nose, cheeks, zygoma, maxilla 561 LF lower facial – lips, intraoral, lower jaw Controls 2 control groups; A 1979 non-head and non-facial (subset of B) B 2209 non-facial
Helmet use	47% cases 57% controls
Results	After adjusting for age, sex, speed and surface – helmets reduced the risk of injury to the upper face (OR O.36) and middle face (0.35) but had no effect on injury to lower face (0.88)
Comments	Data for this study was collected as part of a case-control study of HI resulting from bicycle crashes, Thompson, Rivara et al 1996 88% response to questionnaire Results quoted for A group controls (Authors indicate this overestimates effect and estimates with B controls underestimate effect OR adj(B) 0.43, 0.41, 1.06

Extracted

	Case		Control (A)			
	H	NH	H	NH	Crude OR (CI)	*Adjusted OR (CI)
UF	73	133	1133	846	0.41 (0.30, 0.55)	0.36 (0.26, 0.49)
MF	52	89	1133	846	0.44 (0.31, 0.62)	0.35 (0.24, 0.50)
LF	297	264	1133	846	0.84 (0.70, 1.01)	0.88 (0.72, 1.07)

*Adjusted for age group, sex, speed, and surface

Conclusion	Bicycle helmets offer substantial protection to the upper and mid face in addition to their known protection against HI. Helmets don't offer protection to the lower face Should consider designing helmets with chin protection

Author	Rivara et al
Title	Epidemiology of bicycle injuries and risk factors for serious injury
Year	1997
Journal	Injury Prevention
Country	US
Design	Prospective case control study
Outcome	Presence of serious injury (AIS ISS >8) Presence of neck injury Presence of fatal injury
Subjects	3849 individuals treated in ER (7 hospitals) or dying from bicycle related injuries (1992-94)
Helmet use	51% reported helmet use at the time of crash. Helmet use varied with age: 48% <5 yrs 45% 6-12yrs 32% 13-19yrs 64% >20 yrs
Helmet type	Hard shell Thin shell No shell
Results	7% had serious injury 3% had neck injury 9% admitted 0.4% died Motor vehicles involved in 15% of cases Risk factors for serious injury identified in multivariate logistic regression include: - Young age (<=5) Older age (40+) - Motor vehicle involvement - Speed (>15 mph) Risk for serious injury not associated with helmet use (OR = 0.9 95% CI 0.7-1.2) Risk for neck injury not associated with helmet use (OR = 0.9 95% CI 0.6-1.4) Risk for death associated with non-use of helmets (OR=14.3 95% CI 2.9- 50)
Comments	This study is part of a case-control study of bicycle injuries and helmet effectiveness (Thompson, Rivara et al 96), but able to extract neck injury. Death figures same as extracted for Thompson et al 96 The aim was to identify risk factors for serious injury to bicyclists to determine preventative strategies for injuries not preventable by helmets. Questionnaire response rate 88%

Extracted		Case		Control		
		H	NH	H	NH	Crude OR (CI)	Adj OR (CI)
	NI	48	43	1666	1627	1.09 (0.72,1.65)	0.9 (0.6, 1.4) (age)
	Death	1	13	1717	1659	0.07 (0.01,0.57)	(0.002, 0.4961) Exact

NI = Sprains, cervical spine fractures, cord/nerve root injury, injury to blood vessels

Conclusion	Prevention of serious injuries cannot be accomplished through helmet use alone. Advocates separation of cyclists from motor vehicles and delaying cyclists until children developmentally ready.

<table>
<tr><td>Author</td><td>Jacobson et al</td></tr>
<tr><td>Title</td><td>Bicycle injuries: road trauma is not the only concern</td></tr>
<tr><td>Year</td><td>1998</td></tr>
<tr><td>Journal</td><td>Australian and New Zealand Journal of Public Health</td></tr>
<tr><td>Country</td><td>Australia</td></tr>
<tr><td>Design</td><td>Descriptive study of bicycle injuries</td></tr>
<tr><td>Outcome</td><td>Age, sex
Mechanism of injury
Body part injured (head, upper extremity, lower extremity, trunk)
Type of injury (soft tissue, bone/tendon/joint, concussion)</td></tr>
<tr><td>Subjects</td><td>599 bicycle related injury presentations at A&E 1991-95 at a single hospital in Tasmania
229 with helmet information (1991-92 only)</td></tr>
<tr><td>Helmet use</td><td>50% reported wearing helmets (available 1991-92 only)</td></tr>
<tr><td>Helmet type</td><td>Not specified</td></tr>
<tr><td>Results</td><td>• High proportion of rider only crashes 79%
• High proportion of accidents off road 62%
• High proportion of head injury in younger cyclists, especially no helmet, off road
• Injured riders who had been riding off road were less likely to have been wearing a helmet (38%) than those injured on road (64%).
• Helmet use was relatively less likely in those presenting to A&E with injuries to the head (32%) than with injuries to other body parts (56%)
• Helmet use was lowest in children aged <10.</td></tr>
<tr><td>Comments</td><td>Median age 12 years.
Head injury definition appears to include minor injuries (cuts, abrasions) and facial injuries (since only divided into head and upper extremity)</td></tr>
<tr><td>Extracted</td><td><table>
<tr><td></td><td colspan="2">Case</td><td colspan="2">Control</td><td></td></tr>
<tr><td></td><td>H</td><td>NH</td><td>H</td><td>NH</td><td>Crude OR (CI)</td></tr>
<tr><td>HI</td><td>18</td><td>38</td><td>97</td><td>76</td><td>0.37 (0.20,0.70)</td></tr>
</table>Head injury based on body region (ie head, upper extremity, lower extremity, trunk)</td></tr>
<tr><td>Conclusion</td><td>Rider-only incidents (falls or collisions with stationary objects) are an important public health issue.
Should pursue strategies to increase helmet use for both on and off road riding
More rider education</td></tr>
</table>

Author	Linn et al
Title	Epidemiology of bicycle injury, head injury, and helmet use among children in British Columbia: a five year descriptive study
Year	1998
Journal	Injury Prevention
Country	Canada
Design	Descriptive study
Outcome	Age, sex profile Admissions Location of injury
Subjects	1462 injured bicyclists aged 1-19 presenting hospital ER/ICU 1991-95
Helmet use	22% of patients wore helmets Helmet use lowest among children aged <5yrs and highest among those aged 5-19yrs
Helmet type	Not specified
Results	• Boys injured & admitted more often than girls • More admissions among unhelmeted OR 2.23 (1.39, 3.62) • More head and face injuries among unhelmeted OR 1.55 (1.18, 2.04) • More concussion among unhelmeted OR 4.04 (1.55, 11.47) • No excess of minor head injuries among unhelmeted OR 1.10 (0.60, 2.06) • More dental injuries among unhelmeted, but not sig. OR 1.29 (0.76, 2.20)
Comments	Can't reproduce CI for concussion – must be based on smaller no. of cases. 7% of cyclists in collision with motor vehicles 71% of locations were public roads 12% of cyclists admitted

Extracted

	Case		Control		
	H	NH	H	NH	Crude OR (CI)
HI	15	57	312	1078	0.91 (0.51, 1.63)
HFI	101	467	226	668	0.64 (0.49, 0.83)
BI	1	12	326	1123	0.29 (0.04, 2.22)
C	5	57	322	1078	0.29 (0.12, 0.74)

HI = minor head injuries
HFI = head and facial injuries
C = concussion

Conclusion	A decrease in the number of head injuries and their severity is expected when bicycle helmet use becomes law in British Columbia. The use of helmets can control injuries.

Author	Shafi et al
Title	Impact of bicycle helmet safety legislation on children admitted to a regional pediatric trauma center
Year	1998
Journal	Journal of Pediatric Surgery
Country	US
Design	Retrospective study of bicycle crash victims
Outcome	Helmet use Incidence, type and severity of head injuries, mortality, length of stay, cost
Subjects	208 child bicycle crash victims admitted to a trauma centre 1993-95
Helmet use	15% wore helmets at the time of the crash
Helmet type	Not specified
Results	• Helmet use increased from 2% to 26% after helmet legislation • Proportion of children suffering HI similar in both helmeted and unhelmeted children • Type of head injury different for helmeted and non-helmeted children • Helmet use protected against skull fractures and showed a trend toward reducing intercranial haemorrhages, cerebral contusions and diffuse cerebral edema • Unable to show a statistically significant difference in either the length of stay or the charges for initial hospitalisation.
Comments	Mean age 7 years 5 children who died at the scene of the crash were excluded Authors mention that CDC (US) recommends universal helmet use by all bicycle riders

Extracted

	Case		Control		
	H	NH	H	NH	Crude OR (CI)
HI	21	107	10	70	1.37(0.61, 3.09)
HF	0	23	31	154	0.00(0.00, 0.93)
C	20	77	11	100	2.36(1.07, 5.22)
IC	1	19	30	158	0.28(0.04, 2.15)
BI	21	96	10	81	1.77(0.79, 3.98)
Death	0	3	31	174	0.00(0.00, 14.04) (Exact)

HI = concussion, skull fractures, intracranial injuries, cerebral contusions and oedema
Superficial soft tissue injuries involving the scalp were excluded
HF = skull fractures
C = concussion alone
IC = Intracranial injury
BI = concussion or intracranial injury

Conclusion

- Helmet legislation resulted in a 13-fold increase in use, but use still inadequate
- Helmets reduce the severity of HI and may prevent death from HI
- Helmet use associated with a reduction in skull fractures and a protective trend against intercranial injuries.

Appendix C. References for excluded articles

(This is a reference list for the 47 articles located in the literature search, but excluded from the meta-analysis. See Table 2.)

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