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Overview of Reviews

The promotion of bicycle helmet use in children and youth: an overview of reviews

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Background: Bicycle-related head injuries are a common reason for paediatric emergency department visits. Helmets have been designed to reduce head injuries, and helmet use has been encouraged through mandatory helmet legislation and nonlegislation helmet promotion activities.

Objectives: To synthesize the evidence published in the Cochrane Database of Systematic Reviews regarding bicycle helmet use among children, including helmet effectiveness and methods to promote helmet use.

Methods: The Cochrane Database of Systematic Reviews was searched for all systematic reviews where ‘bicycle*’ or ‘helmet’ appeared in title, abstract or keywords. Reviews were included if they examined paediatric data concerning head injuries among helmeted and nonhelmeted cyclists, helmet use or adverse consequences of helmets. Data pertaining to adults were excluded. Relevant data were extracted, entered into tables and synthesized using qualitative and quantitative methods.

Main results: Three systematic reviews were identified and included 21 observational studies and 14 experimental studies. The methodological quality was assessed in only two of the reviews: the quality was similar in studies examining legislative interventions and several weaknesses were identified in the nonlegislative interventions. Among children, helmet use resulted in a 63% reduction in medically reported head injuries [adjusted odds ratio (OR): 0.37; 95% confidence interval (CI): 0.20, 0.66] and an 86% reduction in the odds of brain injuries (OR: 0.14; 95% CI: 0.05, 0.38). Enactment of mandatory helmet legislation for child cyclists reduced the odds of head injury hospitalizations by 45%, while the odds of head injury hospitalizations reduced by 27% among children in jurisdictions without legislation. There was a significant reduction in traumatic brain injury among children cycling after the passage of helmet legislation (OR: 0.82; 95% CI: 0.76, 0.89); however, there was no significant decrease in other head and facial injuries post-legislation (OR: 1.08; 95% CI: 0.90, 1.23). Legislation also resulted in a significant increase in the number of children observed wearing a helmet (prevalence ratio: 3.69; 95% CI: 2.65, 5.14). Compared with children who received no intervention, those who received nonlegislative helmet promotion activities had a significant increase in observed helmet wearing (OR: 2.08; 95% CI: 1.29, 3.34), self-reported helmet wearing (OR: 3.27; 95% CI: 1.56, 6.87) and self-reported helmet ownership (OR: 2.67; 95% CI: 0.89, 8.03). No adverse events were associated with helmet use among cyclists.

Authors’ conclusions: Bicycle helmets appear to be an effective way to reduce head injuries among children. Interventions to increase helmet use may be effective, particularly community-based, school-based, and those that provide free helmets; however, no effect of the interventions on helmet use were reported in randomized controlled trials. Finally, helmet legislation appears to be effective in increasing helmet use and reducing head injuries.

Keywords: bicycle helmets, head injury, legislation, prevention, promotion

Plain language summary

Children often hurt their heads when they fall off their bicycles. Bicycle helmets have been shown to reduce the risk of head injuries; however, all cyclists do

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not wear helmets. Mandatory helmet laws and helmet promotion activities have been used to increase bicycle helmet use.

Three systematic reviews were identified that examined the effectiveness of helmets and ways to promote their use. Helmets significantly reduced the odds of traumatic brain injuries (TBIs) in children. Places with helmet legislation reported significantly fewer head injuries when compared with places with no such legislation. Bicycle helmet promotion activities significantly increased children reporting wearing a helmet, children observed wearing a helmet and owning a helmet. There were no adverse events associated with bicycle helmet use. Bicycle helmets reduce head injuries and their use can be encouraged through legislation or health promotion activities.

Background

Cycling is a popular form of transportation and recreation; however, there is morbidity and mortality associated with cycling injuries. The rate of cycling mortality among children is 0.16 per 100 000 children or 0.55 per million miles travelled, a rate 55 times higher than automobile deaths per million miles travelled (1). Helmets have been shown to reduce head injuries among cyclists and a variety of strategies have been implemented to encourage helmet use.

Description of the condition

Head injuries make up a substantial proportion of cycling injuries and result in substantial treatment and societal costs. Of all sport-related head injuries presenting to the Emergency Department, approximately 12% of the head injuries were attributed to cycling (2). Powell and Tranz estimated the rate of head trauma presenting to the Emergency Department among American children aged 1–14 years to be 7.3 per 10 000 children (3). Among children presenting to the Emergency Department following a cycling injury, 22–40% had sustained a head injury and the majority of children were not wearing a helmet (4–6). Approximately 40% of children who were admitted to the hospital or died owing to a cycling-related injury had experienced head trauma (7).

Description of the interventions

A variety of manufacturers sell helmets specifically designed for cycling, and they are widely available for purchase at many cycling shops in most countries.

There are two ways that helmet use can be encouraged: mandatory helmet legislation and nonlegislative helmet promotion. Legislation has been passed at the municipal, provincial/state and national levels in countries including Australia, Canada, New Zealand and the US. The helmet laws require either children only or the entire population to wear a helmet when cycling. The fines for cycling without a helmet are variable. For example, Canadian fines range from $5 (Yorkton, Saskatchewan) to a maximum of $128.75 (Nova Scotia) (8).

Alternatively, helmet use can be promoted through nonlegislative initiatives. These include receiving free or subsidized helmets, health promotion programs or educational programs informing cyclists of the benefits of wearing a helmet. The health promotion campaigns can be delivered in a variety of settings, such as communities, schools and physicians' offices.

How the interventions might work

Helmets are comprised of two components: a hard exterior shell and a soft interior liner. In the event of a crash, the head is protected as the helmet reduces the rate that the brain and skull accelerate or decelerate at the time of impact (9). There are a variety of international bicycle helmet standards and each helmet is certified and marked as meeting at least one standard (10–12).

Interventions (or prevention strategies) can be classified into two categories: active and passive (13). Active interventions require the cyclists to modify their behaviour by choosing to wear a helmet. Such behavioural modification can be encouraged, for example by offering educational programs or free or subsidized helmets. This approach may be less effective compared with a passive approach, such as mandatory helmet legislation. Passive interventions are environmental or legislative changes that protect a greater number of cyclists. The effectiveness of helmet legislation may be diminished if such laws are not enforced or if the penalty is not perceived as a deterrent to warrant helmet use.

Why it is important to do this overview

Helmets have been shown to reduce the risk of bicycle-related head injuries, but despite their effectiveness, helmets are not uniformly used. A greater understanding of strategies to encourage and promote helmet use among children is needed to ensure that as many cyclists are protected from head injuries as possible.

Objectives

To synthesize the evidence published in the Cochrane Database of Systematic Reviews regarding bicycle helmet use among children, including helmet effectiveness and methods to promote helmet use.

Methods

Criteria for considering reviews for inclusion

Reviews were included provided they were published in the Cochrane Database of Systematic Reviews,

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examined the effectiveness of bicycle helmets or methods to promote their use, and reported results for a paediatric population (<18 years of age).

Search methods for identification of reviews

Issue 6, 2011 of the Cochrane Database of Systematic Reviews was searched using the terms 'bicycle*' or 'helmet' restricted to the title, abstract or keywords.

Outcome measures

The following a priori outcomes were identified: mortality, head injury, observed helmet use, self-reported helmet use, self-reported helmet ownership and adverse consequences (reduced cycling participation and increased risk-taking behaviour).

Data collection and analysis

One reviewer (KR) extracted the following information from each of the included reviews: inclusion criteria (population, intervention, comparisons and outcomes), characteristics of included reviews and quality assessment, and numeric results. A second reviewer (MF) independently verified accuracy and completeness of all of the extracted information. Review Manager 5 was used for all statistical analyses (14).

Because many of the included studies in the reviews employed an observational study design, dichotomous data were summarized using odds ratios (ORs) with 95% confidence intervals (CIs). The OR describes the odds of the event occurring in the exposed group compared with the odds of the event occurring in the unexposed group and is interpreted as statistically significant if the 95% CI does not cross 1. For all pooled effect estimates, the accompanying I^2 values were reported and represent the degree of statistical heterogeneity between studies. An I^2 value close to 0% indicates minimal or no heterogeneity among the studies, whereas an I^2 of 50% or greater represents substantial heterogeneity (15). All of the pooled estimates were directly extracted from the systematic reviews and no recalculations were needed. If a review reported results using other summary estimates, such as a prevalence ratio or rate difference, the results were reported in the original summary estimate provided in the review.

If an effect estimate was not reported or could not be calculated because the number of participants in each group was not reported, the data were transcribed as they were reported in the review (i.e. rates or percentages). Results were reported as statistically significant, not significant or not reported.

Results

Results of the search

The search resulted in 11 completed reviews and one protocol. Seven reviews were excluded because they did not include a paediatric population. An eighth review examined visibility aids for preventing bicycle accidents; however, the individuals observing the cyclists were adults and in the eight retrieved studies, all the cyclists were adults (the remaining two studies could not be retrieved). The Cochrane Injuries Group was contacted to confirm that no relevant reviews were missed. One review was in the process of being updated and the most up-to-date, unpublished version of the review was provided by the authors (16).

Methodological quality of the studies included in the reviews

Two reviews employed different tools to assess methodological quality (16,17), and methodological quality was not assessed in the third review (18). The legislative review assessed quality using the previously validated 27-point Downs and Black tool that assesses five domains of quality: reporting, bias, confounding, external validity and power. Three of the studies earned a score of 19/27 and the other three studies scored 20/27 (17). The majority of methodological limitations referred to lack of randomization and blindness (which was not possible given the nature of the intervention) and not measuring compliance or adverse events.

The second review examining nonlegislative approaches to helmet promotion assessed methodological quality by study design. For randomized controlled trials (RCTs), quality markers include allocation concealment, blinding of outcome assessment and completeness of follow-up. Of the 14 trials, three reported adequate concealment (21%), one reported inadequate concealment (7%), and concealment methods were unclear in the remaining 10 trials (71%). Only three of the studies reported blinding of outcome assessment (21%) and remaining 11 studies did not assess outcomes in a blinded manner (79%). Eight of the 14 trials reported information about follow-up (57%), five studies did not report follow-up information (36%), and it was unclear in the remaining study (7%). The methodological quality of non-RCTs was determined by blinding of outcome assessment, completeness of follow-up and distribution of confounders. No study assessed outcomes in a blinded manner. Reporting of details concerning follow-up was variable: four studies reported follow-up (29%), two studies did not report it (7%), four studies did not mention it (29%), and it was not applicable in four studies because they were population based (29%). The majority of studies reported information about potential confounders (8/14; 64%). An adjustment for clustering was not reported in any of the cluster RCTs or controlled before-after studies.

Description of included reviews

Three systematic reviews were included in this overview. One review examined the role of nonlegislative strategies to promote bicycle helmet use (16), a

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second studied the role of legislation on helmet use and helmet effectiveness (17) and the third review examined the effectiveness of helmets for the prevention of head and facial injuries (18). The characteristics of the included reviews are provided in Table 1.

The included reviews were published between 2005 and 2010 but the authors of the review assessing nonlegislative strategies provided us with an updated, yet-to-be-published version of their review. The literature searches for included studies were conducted between 2006 and 2009. While the three reviews included 42 studies, only 35 studies included paediatric data. It was not possible to determine the total number of children who were included in the studies. The reviews included a variety of study designs conducted in children: five RCTs (nonlegislative review), eight cluster RCTs (nonlegislative review), one quasi-RCT (nonlegislative review), one case–control study (helmet review), two case-controlled before-after studies (legislative review) and 18 controlled before-after studies (14 included in the nonlegislative review and four in the legislative review).

Search methods

All three reviews conducted extensive literature searches. Each review searched CENTRAL, MEDLINE, EMBASE and CINAHL. In addition, each review searched between seven (18) and nine (16) additional electronic databases. Unpublished studies were sought via a variety of methods: all three reviews examined reference lists, two conducted hand-searching of relevant journals and/or conference proceedings (17,18) and two reviews contacted experts in the field (16,17). Government websites (17) and the Internet (16) were also searched.

Participants

The included participants differed among the three reviews. Macpherson *et al.* included the entire population, helmet use and head injuries were examined in children, and results were compared with those of adults when the helmet legislation only applied to children. Owen *et al.* included all children between the ages of 0–18 years of old. Thompson *et al.* included bicyclists of all ages who sustained a crash or fall while riding a bicycle.

Interventions

All three reviews included interventions aimed at promoting helmet use and/or decreasing head injuries, including mandatory helmet legislation (17), nonlegislative helmet promotion activities (16) and helmet use (18). While two reviews compared the intervention to no intervention, Owen *et al.* compared nonlegislative health promotion activities with either no intervention or less intense helmet promotion activities. The health promotion activities included bicycle helmet promotion in conjunction with other health promotion topics, such as smoke alarm use and seat belt use. Nonlegislative health promotion activities included receiving free helmets, subsidized helmets, education or counselling and media campaigns.

Outcome measures

No review specified an a priori primary outcome. Two reviews measured both helmet use and head injury (17,18) while the last review only assessed helmet use and ownership (16). The length of follow-up for observed and self-reported helmet use varied from two weeks to two years and was not reported in one study (16).

Head injuries were defined in a variety of ways: a diagnosis of head injury (brain injury, fractures, concussion, scalp lacerations and facial injuries) by a health-care professional (17) or any injury to the scalp, skull or brain (18). Brain injuries were further described as any brain injury, indicated by loss of consciousness or other evidence of brain injury or dysfunction, or severe brain injury defined as an Abbreviated Injury Score $\geq$3 (18). Only one review included facial fractures or lacerations (18).

Data analysis

Only the review examining nonlegislative interventions conducted a meta-analysis using random effects modelling and the one trial that included children and adults was not included in the original meta-analysis (16). For the remaining two reviews, substantial methodological heterogeneity precluded conducting a meta-analysis and results from the individual studies were presented (17,18).

Effects of the interventions

Head, facial, brain injuries and mortality

Two reviews examined the effectiveness of helmets (17,18) and the results are provided in Table 2. Results from a case–control study found a significant reduction in medically reported head injuries among Australian children less than 15 years who wore helmets compared with those who did not wear helmets (adjusted OR: 0.37; 95% CI: 0.20, 0.66). This represents a 63% reduction in the odds of a head injury. There was also an 86% reduction in the odds of brain injuries among helmet users compared with nonhelmet users (OR: 0.14; 95% CI: 0.05, 0.38).

In a controlled before-after study, paediatric head injuries requiring hospitalization were compared among Canadian provinces with and without mandatory bicycle helmet legislation for children aged 5–19 years. Prior to legislation, the rate of head injuries was 18.27 per 100 000 and decreased to 9.96 per 100 000 post-legislation, resulting in a 45% reduction in the rate of head injuries. During the same time period, the head injury rate among children living in

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Table I. Characteristics of included reviews

Review title Authors Last assessed as up-to-date	Number of studies (children only) Study design	Pooled sample size (range)	Population	Intervention	Comparison	Outcomes for which data are reported
Helmets for preventing head and facial injuries in bicyclists Thompson DC, Rivara F, Thompson R November 2006	7 (1) One case–control	All studies 7 253* (445–3390) Studies with children only: 445	Bicyclists of all ages who have crashed or fallen while riding a bicycle	Any type of bicycle helmet, including hard shell, thin shell or no shell	No bicycle helmet	Head injury and brain injury
Bicycle helmet legislation for the uptake of helmet use and prevention of head injuries Macpherson A, Spinks A September 2009	6 (6) Four CBA Two case-controlled before-after	Not reported	The whole population	Bicycle helmet legislation	No bicycle helmet legislation	Mortality, head injury, helmet use (self-reported and observed) and adverse consequences
Nonlegislative interventions for the promotion of cycle helmet wearing by children (in press) Owen R, Kendrick D, Mulvaney C, Coleman T, Royal S April 2009	29 (28) 14 CBA Eight cluster RCTs Five RCTs One quasi-RCT	Not reported	Children and adolescents 0–18 years of age (one trial included participants up to 20 and 24 years of age)	Interventions to promote bicycle helmet use that do not require enactment of legislation, including health education programmes, subsidized or free helmet distribution, media campaigns or interventions that included elements of the above	No interventions or less intensive interventions to promote bicycle helmet use	Observed bicycle helmet wearing, self-reported bicycle helmet ownership and self-reported bicycle helmet wearing

* Pooled sample size is based on five studies presented in seven publications.
CBA: controlled before-after study; RCT: randomized controlled trial.

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Table II. Head, facial and brain injuries

Outcome	Comparison	Number of participants (studies)	Odds ratio (95% confidence interval)	I^2	Comparison favoured
Head and/or facial injury	**Helmet versus no helmet**	**445 (1)**	**0.37 (0.20, 0.66)***	—	Helmet use
	Post-legislation versus pre-legislation	17714 (1)	1.08 (0.90, 1.23)†	—	—
Brain injury	**Helmet versus no helmet**	**445 (1)**	**0.14 (0.05, 0.38)**	—	Helmet use
	Post-legislation versus pre-legislation	**17714 (1)**	**0.82 (0.76, 0.89)†**	—	Helmet legislation

* Adjusted odds ratio;
† 99% confidence intervals.

provinces without legislation decreased from 18.35 to 13.33 per 100 000, representing a 27% reduction.

A case-controlled before-after study using California patient discharge records found a significant reduction in TBIs requiring hospitalization among children after the enactment of a mandatory helmet policy that applied to cyclists less than 18 years (OR: 0.82; 95% CI: 0.76, 0.89), indicating that helmet legislation reduced TBI by 18% (95% CI: 11.5, 24.3%). However, there was no significant reduction in other head and facial injuries post-legislation (OR: 1.08; 95% CI: 0.90, 1.23). Also, there was no significant reduction in TBI or other head and facial injuries among adults who were not legally required to wear a helmet while cycling.

One controlled before-after study used coroner's data to examine the association between all-cause mortality and helmet use in Ontario. After mandatory helmet legislation that applied to children less than 16 years, there was a statistically significant reduction in the odds of all-cause mortality by 52%. There was no corresponding reduction in all-cause mortality among adults who were not affected by the mandatory helmet legislation. The proportion of deaths due to head injury versus other injuries was not reported.

Observed helmet wearing

Results pertaining to observed helmet wearing are provided in Table 3. Two controlled before-after studies observed helmet-wearing pre- and post-legislation applied to children. One study conducted in Alberta, Canada, found that mandatory helmet legislation significantly increased observed helmet wearing after adjusting for the confounding effects of gender, age and average annual income (prevalence ratio: 3.69; 95% CI: 2.65, 5.14). No such increase was observed among adults. The second study, conducted in rural Georgia, examined the role of police enforcement in a rural community with mandatory helmet legislation for children. Prior to enforcement, no child was observed wearing a helmet while cycling. During the five-month enforcement period, 45% of children wore a helmet (range 30–71%) and 54% of children were wearing a helmet while cycling at two years post-enforcement. At two years, 15% of adolescents (13–15 years) were observed wearing a helmet and no adults. Helmet observations made prior to legislation found no cyclist wore a helmet.

Eleven studies measured observed helmet wearing among children who did and did not receive helmet promotion activities. Those who received nonlegislative helmet promotion activities had a significantly increased odds of observed helmet wearing compared with those who did not receive any helmet promotion activities (OR: 2.08; 95% CI: 1.29, 3.34; eight controlled before-after studies and three RCTs). However, nonlegislative helmet promotion activities had no effect on observed helmet wearing (OR: 0.99; 95% CI: 0.18, 5.63) when limited to the three RCTs. The odds of observed helmet wearing were higher when the nonlegislative helmet promotion activities were delivered in a community setting (OR: 4.30; 95% CI: 2.24, 8.25; four controlled before-after studies) versus a school-based setting (OR: 1.73; 95% CI: 1.03, 2.91; five controlled before-after studies and three RCTs). Providing free helmets as a component of received nonlegislative helmet promotion activities resulted in higher odds of observed helmet wearing (OR: 4.35; 95% CI: 2.13, 8.89; two controlled before-after studies) than education only (OR: 1.43; 95% CI: 1.09, 1.89; two controlled before-after studies and one RCT). There was no significant association between observed helmet wearing and nonlegislative helmet promotion among children who received subsidized helmets and those who did not (OR: 2.02; 95% CI: 0.98, 4.17; five controlled before-after studies and two RCTs).

In two controlled before-after studies, the manner in which data were reported precluded meta-analytic techniques. In one study, observed helmet wearing increased from 0% at baseline to 10% at follow-up among children who received a school-based program that included free helmets to children who applied for them (statistical significance was not reported). In the second study examining the effectiveness of education and subsidized helmets, observed helmet wearing significantly increased from 3.5% at baseline to 33.3% at 10-week follow-up; the concurrent increase among the control school that received no intervention was not significant (6.3–10.9%).

Self-reported helmet wearing

Table 4 describes the results of self-reported helmet wearing. One case-controlled before-after study measured self-reported helmet wearing pre- and post-legislation. After legislation, Californian children who

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Table III. Observed helmet wearing

Comparison	Number of participants (studies)	Odds ratio (95% confidence interval)	I^2 (%)	Comparison favoured
Any nonlegislative intervention versus control	**3000 (11)**	**2.08 (1.29, 3.34)**	**67**	**Any nonlegislative intervention**
Any nonlegislative intervention versus control: RCT only	807 (3)	0.99 (0.18, 5.63)	64	—
Community-based intervention versus control	**473 (4)**	**4.30 (2.24, 8.25)**	**0**	**Community-based intervention**
School-based intervention versus control	**2621 (8)**	**1.73 (1.03, 2.91)**	**71**	**School-based intervention**
Free helmets versus control	**318 (2)**	**4.35 (2.13, 8.89)**	**0**	**Free helmets**
Subsidized helmets **versus** control	1804 (7)	2.02 (0.98, 4.17)	70	—
Education only versus control	**1631 (3)**	**1.43 (1.09, 1.88)**	**0**	**Education only**
Any nonlegislative intervention versus control (1–12 years old)	**1169 (5)**	**2.50 (1.17, 5.37)**	**68**	**Any nonlegislative intervention (1–12 years old)**
Post-legislation versus pre-legislation	**205* (1)**	**Prevalence ratio: 3.69 (2.65, 5.14)***	—	**Helmet legislation**

* Prevalence of helmet use in adult controls did not change (prevalence ratio not reported). Adjusted prevalence ratio (sex, age, average annual income).

Table IV. Self-reported helmet wearing

Comparison	Number of participants (studies)	Odds ratio (95% confidence interval)	I^2 (%)	Comparison favoured
Any nonlegislative intervention versus control	**1850 (9)**	**3.27 (1.56, 6.87)**	**85**	**Any nonlegislative intervention**
Any nonlegislative intervention versus control: RCT only	1255 (5)	3.02 (0.72, 12.67)	91	—
School-based intervention versus control	**1292 (6)**	**4.21 (1.06, 16.74)**	**90**	**School-based interventions**
Free helmets versus control	**501 (3)**	**7.27 (1.28, 41.44)**	**90**	**Free helmets**
Education only versus control	**1380 (7)**	**1.93 (1.03, 3.63)**	**58**	**Education only**
Intervention in health care setting versus control	**222 (2)**	**2.78 (1.38, 5.61)**	**0**	**Interventions in health care settings**
Any nonlegislative intervention versus control (1–12 years old)	1257 (4)	1.44 (0.82, 2.51)	64	—
Any nonlegislative intervention versus control (11–18 years old)	**410 (3)**	**4.99 (1.68, 14.83)**	**33**	**Any nonlegislative interventions (11–18 years old)**
Pre-legislation versus post-legislation	**510 (1)**	**1.84 (1.48, 2.28)***	—	**Helmet legislation**

* The odds of using a helmet did not change in adult controls (OR: 1.17; 95% CI: 1.00, 1.38).

were injured while cycling reported a significant increase in helmet use (OR: 1.84; 95% CI: 1.48, 2.28) and a near-significant increase among adults who were unaffected by legislation (OR: 1.17; 95% CI: 1.00, 1.38).

Nine studies examined the effects of nonlegislative helmet promotion activities on self-reported helmet wearing and the pooled estimate indicated that there was a 3.27 increased odds (95% CI: 1.56, 6.87; three controlled before-after studies, one quasi-RCT and five RCTs) of self-reported helmet wearing among children who received nonlegislative helmet promotion activities compared with those who did not. When the pooled analysis was limited to five RCTs, there was no longer a significantly increase in odds of self-reported helmet wearing among children who received nonlegislative helmet promotion activities. Promotion activities that were delivered in a school or health-care setting, or included free helmets or education all resulted in a significant increase in the odds of self-reported helmet wearing among children who received nonlegislative helmet promotion activities. The nonlegislative helmet promotion activities were efficacious among children 11 years or older (OR: 4.99; 95% CI: 1.68, 14.83; one controlled before-after study and two RCTs); however, there was no significant increase in self-reported helmet wearing among children 12 years or younger (OR: 1.44; 95% CI: 0.82, 2.51; two controlled before-after studies and two RCTs). With the exception of helmet promotion activities provided in a health-care setting and to children aged 11–18, all the pooled analyses exhibited statistical heterogeneity greater than 50%.

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Five studies assessed self-reported helmet use but data was not reported in such a way that it could be incorporated into the meta-analysis. In a cluster RCT, there was no significant difference in self-reported helmet wearing between children who received a helmet and education pack when compared with those who received a helmet, education pack, assembly, lesson and invitation to a cycling event (OR: 0.98; 95% CI: 0.57, 1.68). There was no association between free helmets versus co-payment with respect to self-reported helmet wearing (adjusted OR: 1.66; 95% CI: 0.94, 2.92; RCT). At five-years follow-up of a controlled before-after study, children aged 11–15 years who lived in a campaign area increased their self-reported helmet use from 11% at pre-campaign to 31% at five-year follow-up and there was no change among those who lived in a campaign-free area ($p < 0.001$). Elementary school children participated in a controlled before-after study and received intensive education and a subsidized helmet or basic education and a subsidized helmet; there was no significant difference in self-reported helmet wearing (data not provided). Evidence from an RCT found that free helmets plus education resulted in a significant increase in self-reported helmet use compared with education only ($p < 0.01$).

Self-reported helmet ownership

Table 5 includes the results regarding self-reported helmet ownership. Compared with no intervention, nonlegislative helmet promotion activities did not increase self-reported helmet ownership among children (OR: 2.67; 95% CI: 0.89, 8.03; three controlled before-after studies and four RCTs). This finding was replicated when the pooled analysis included only the four RCTs versus RCTs and observational studies. There was also no association between nonlegislative helmet promotion activities and self-reported helmet ownership when the promotion activities were delivered in the community, school or health-care setting or by age. Promotion activities that included a free helmet did significantly increase the odds of self-reported helmet ownership (OR: 11.63; 95% CI: 2.14, 63.16; two controlled before-after studies and one RCT). However, education only activities failed to significantly increase the odds of self-reported helmet ownership. The majority of the comparisons exhibited substantial statistical heterogeneity.

Two studies were not included in the meta-analysis. In an RCT, there was no significant increase in the odds of helmet ownership among children who received a helmet and education pack versus a helmet, education pack, assembly, lesson and invitation to a cycling event (OR: 1.51; 95% CI: 0.50, 4.58), although providing free helmets did result in reducing inequalities of helmet ownership among disadvantaged areas. A controlled before-after study found that there was no significant difference in helmet ownership among elementary school children who received a subsidized helmet and intensive or basic education.

Adverse consequences

One review examined adverse consequences associated with helmets (17). Two studies compared head injuries to nonhead injuries before and after legislation. While there was a significant decrease in the odds of TBI after California's legislation compared with pre-legislation (OR: 0.82; 95% CI: 0.76, 0.89), there was a significant increase in the odds of a nonhead injury post-legislation compared with pre-legislation (OR: 1.09; 95% CI: 1.05, 1.13). A second study conducted in Ontario found a greater decrease in the ratio of head to other injuries among provinces with legislation (ratio difference: 0.26; 95% CI: 0.25, 0.27) and provinces without legislation (ratio difference: 0.04; 95% CI: 0.03, 0.05).

Discussion

Summary of main results

Helmets are effective in reducing head injuries. All three case–control studies that examined this association reported a protective effect. Mandatory helmet legislation is associated with a decrease in bicycle-related brain injuries compared with no legislation, and this was shown in all of the studies that examined this association. Finally, nonlegislative interventions can be effective in increasing observed helmet use, particularly community-based interventions compared to no

Table V. Self-reported helmet ownership

Comparison	Number of participants (studies)	Odds ratio (95% confidence interval)	I^2 (%)	Comparison favoured
Any nonlegislative intervention versus control	1529 (7)	2.67 (0.89, 8.03)	91	—
Any nonlegislative intervention versus control: RCT only	1044 (4)	1.58 (0.66, 3.77)	82	—
Community-based intervention versus control	426 (2)	5.65 (0.82, 38.98)	88	—
School-based intervention versus control	395 (3)	1.03 (0.60, 1.76)	9	—
Free helmets versus control	**556 (3)**	**11.63 (2.14, 63.16)**	**87**	**Free helmets**
Education only versus control	794 (3)	1.00 (0.60, 1.66)	0	—
Intervention in health care setting versus control	803 (3)	3.84 (0.46, 32.36)	94	—
Any nonlegislative intervention versus control (1–12 years old)	726 (4)	2.09 (0.47, 9.25)	91	—

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interventions, interventions that include a free helmet and interventions in schools. A note of caution about nonlegislative interventions is warranted – there was no effect of nonlegislative interventions when conducted in the context of an RCT, suggesting that some of the effects may be confounded by nonmeasured variables.

Limitations

The primary limitation of this body of research is related to the quality of included studies. Only 13 studies were RCTs or cluster RCTs, and even in those blinding was not possible. The other controlled before-after and case–control studies could not be conducted using a randomized design. In particular, it is impractical to try to assign legislation randomly. Not surprisingly, there was substantial variation between the studies (as indicated by I^2 statistic of greater than 50% in some instances), both in terms of study design and in terms of the interventions studied. A further limitation is the lack of evidence related to adverse events. While adverse events were examined in the review by Macpherson and Spinks, there was a paucity of evidence available. Finally, all of the studies were conducted in high income countries and this limits the generalizability to other parts of the world.

Agreements and disagreements

Opponents of mandatory helmet use raise concern that legislation will result in people cycling more recklessly or less frequently among those who perceive the legislation as unnecessary. Risk compensation, or risk homeostasis, refers to the idea that each person has an acceptable level of tolerable risk and if their level of risk is reduced (e.g. by wearing a helmet), they will alter their behaviour to increase their risk to their acceptable level (e.g. by cycling faster) (19). There are two ways that risk compensation can be operationalized among cyclists. Cautious cyclists wear helmets and it is this cautious personality (and not helmet use) that results in fewer injuries. However, Thompson *et al*. found an 85% reduction in paediatric head injuries, after adjusting for age, experience and crash severity (20). The authors argue that adjusting for these factors would have controlled for the possibility that cautious cyclists are more likely to wear helmets. Providing researchers adjust for crash severity circumstances, the comparison between risk of head injury among those who did and did not wear a helmet is valid because a cautious personality should not predict a head injury versus nonhead injury once a crash has occurred (21). In contrast, Farris *et al*. found that helmeted cyclists were significantly more likely to use hand signals and make legal stops compared with nonhelmeted cyclists, indicating that cautious people may be more likely to wear a helmet (22). Others found that nonhelmeted cyclists were over seven times more likely to sustain a severe nonhead/neck injury when involved in a motor vehicle collision than helmeted cyclists (23). This suggests that cautious cyclists wear helmets more than noncautious cyclists, as helmets are not protective for nonhead/neck injuries. The abovementioned studies were conducted in adult populations and it is unclear if the results can be generalized to children.

The second possible operationalization of risk compensation is that helmeted cyclists will cycle more dangerously than nonhelmeted cyclists to compensate for the protection offered by the helmet (24). Thompson found that if risk compensation was operating, high-risk taking helmeted cyclists would have acted four times as risky to overcome the protective effect of helmets. Rivera *et al*. compared serious and nonserious injuries among cyclists and found that after controlling for other predictors of serious injury, helmet use was not significantly associated with serious injury and risk compensation did not occur (6).

It has been hypothesized that mandatory helmet laws discourage cycling. Robinson compared the number of observed cyclists before and after legislation at the same location and under similar weather conditions (25). Cycling rates declined one and two years post-legislation. The authors argued that bike helmet legislation in Australia deterred people from cycling and this health consequence outweighed the increased number of helmeted cyclists and decreased number of head injuries (25). However, it has been estimated that compared with sedentary people, cyclists must cycle either 40 km a week or an hour each week to reduce the risk of coronary heart disease (26). Thus, an association between helmet laws and cycling rates would assume that avid cyclists will stop cycling because of helmet legislation, rather than casual cyclists who are less likely to obtain true cardiovascular health benefits from cycling (27). A survey of American bicycle commuters found that 87% of cyclists always wore their helmet and the average commute was 11.6 km and took approximately 30 minutes, suggesting that many bicyclists who use bicycles for transport rather than recreation are not deterred by helmet legislation (28). Most of this research is related to adults, however, and may not apply to child bicyclists.

Authors' conclusions

Bicycle helmets appear to be an effective way to reduce head injuries among children. All of the studies that examined the association between helmet use and head injury found a protective effect. Further, interventions to increase helmet use may be effective, particularly community-based, school-based and those that provide free helmets, but it is worth noting that no effects of the interventions on helmet use were reported in RCTs. Finally, helmet legislation appears to be effective in increasing helmet use and reducing head injuries.

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Implications for practice

Any health professional involved with child health should recommend that children wear bicycle helmets when cycling. Nonlegislative interventions to promote helmet use can work, but are not always successful. Legislation has been effective in increasing helmet use and reducing brain injuries, so practitioners involved with prevention of injury can work towards the enactment of helmet legislation in jurisdictions where such legislation does not exist.

Implications for research

Although the evidence for the effectiveness of bicycle helmets is robust, evidence for the optimal method for promoting bicycle helmet use is of lesser quality. Ongoing studies about helmet use are still necessary. In particular, evidence is required around the optimal format for nonlegislative interventions, particularly RCTs based on best practices including community and school-based interventions. Ongoing research about best practices for helmet laws is also needed. For example, helmet laws that apply to all ages may be more effective than those that apply to children only (29). Finally, all future research should consider possible adverse effects of helmet promotion to be able to better assess the potential impact on all aspects of health.

Contributions of authors

KR extracted the data and wrote the introduction, methods, results and a portion of the discussion. MF checked the data extraction and reviewed drafts of the manuscript.

PP and AM wrote parts of the discussion, reviewed drafts of the manuscript and provided clinical expertise.

Declarations of interest

AM is the first author of one of the reviews included in this article. PP is an author on five of studies that were included in two of the reviews and AM is an author of one study and one of the systematic reviews.

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