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Prevention of bicycle-related injuries in children and youth: a systematic review of bicycle skills training interventions

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ABSTRACT

Background Bicycling is a popular means of recreation and transportation for children; however, it is a leading cause of recreational injury. Bicycle skill development and safety education are important methods of bicycle injury prevention.

Objective To determine the effectiveness of bicycle skills training programmes in reducing bicycle-related injuries in children and youth.

Methods Sixteen databases were systematically searched to include studies involving children less than 19 years of age who participated in interventions that targeted bicycle skills and safety education. Outcome measures included injury, behaviour, knowledge and attitudes. Data extraction included study characteristics, intervention and outcomes. Quality of evidence was assessed using the Downs and Black criteria.

Results Twenty-five studies, including both observational (ie, case–control) and experimental (ie, randomised controlled trials) designs met the inclusion criteria. Overall, there was no statistically significant intervention effect on measures of injury. Eight of 16 studies measuring knowledge reported significant knowledge gains as a result of the intervention. Of 13 studies evaluating behavioural and attitude changes, five reported significant improvement. There was no significant difference in quality index scores between studies that showed an improvement in knowledge or behaviour (61%, 95% CI 49% to 74%) and studies that did not (57%, 95% CI 48% to 66%).

Conclusions There is a paucity of high-quality research in the area of bicycle skills training programmes. Educational and skills training bicycling programmes may increase knowledge of cycling safety, but this does not seem to translate into a decrease in injury rate, or improved bicycle handling ability and attitudes.

INTRODUCTION

Bicycling is a popular means of recreation, exercise and transportation for children and youth worldwide. There are more than 800 million bicycles in the world, twice the number of motor vehicles.[1] In Canada, it is estimated that 80% of children under 12 years of age ride a bicycle.[2] Only 20% of bicycle-related injuries requiring hospitalisation involve motor vehicle collisions; however, such collisions represent over 90% of all fatal cycling-related injuries.[2]

A primary strategy to prevent bicycle-related injuries is the promotion of bicycle helmet use. A Cochrane systematic review showed that helmet use reduces the risk of head injury by up to 88% and facial injuries by up to 65% for cyclists of all ages.[3] In addition, reviews examining legislative and non-legislative helmet interventions demonstrate that both approaches are effective in increasing helmet use.[3–5]

Other strategies to prevent bicycle-related injuries include environmental modification, education and skills training. Environmental modifications may include the installation of marked bicycle lanes, on-road bike routes or off-road bicycle paths. A recent systematic review reported that purpose-built bicycle-specific lanes reduce crashes and injuries among cyclists.[6] Educational and skills intervention strategies often focus on helmet use, but may also extend to bicycle skills training courses of varied duration, from 1-day bicycle rodeos (ie, a clinic that aims to educate children about rules and behaviours associated with safe cycling) to long-term courses integrated with school curricula.[7 8] It has been hypothesised that these training programmes may reduce the frequency of bicycle-related injuries through increased knowledge and compliance with traffic regulations, along with enhanced bicycle handling skills.[9] Skills training may be an important approach for vulnerable road users including cyclists and pedestrians who account for approximately 46% of global road traffic deaths.[10] To our knowledge, there has not been systematic evaluation of the effectiveness of bicycle skills training programmes. Therefore, the primary objective of this systematic review was to determine the effectiveness of bicycle skills training programmes in preventing bicycle-related injuries in children and youth aged 0–18 years.

METHODS

Data sources

Data capture and manuscript preparation have followed PRISMA guidelines (see supplementary appendix A, available online only; figure 1). In collaboration with a research librarian, comprehensive search strategies including combinations of medical subject headings and keywords were developed (table 1). The following electronic databases were systematically searched: BIOSIS, Canadian Research Index, CENTRAL, CINAHL, Dissertations & Theses, EBM Reviews, EMBASE, ERIC, ISI Web of Science, LILACS, MEDLINE, PsycINFO, SCOPUS, SafetyLit and TRANSPORT. All databases were searched from inception and the search is up to date as of February 2013. The journals *Injury Prevention*, *Accident Analysis and Prevention* and *Pediatrics* were hand-searched for relevant articles published from July 2007 to July 2012. Reference

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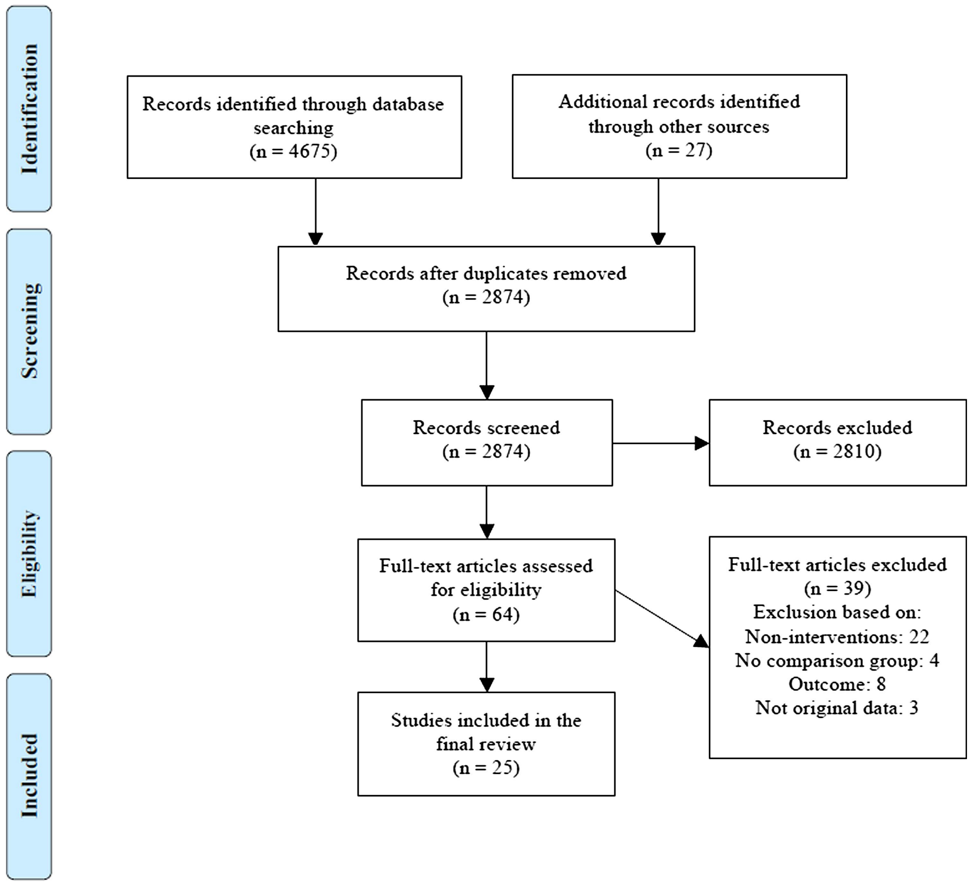

Figure 1 Flow diagram of study selection for inclusion in the systematic review.

lists from relevant studies were examined in addition to a grey literature search of government agencies, traffic and road accident research bodies and injury prevention organisations.

Table 1 Sample search strategy

1	Bicycling/ or (bicycl* or bike* or cyclist or cycling).mp. (50 000)
2	accident prevention/ or safety/ or safety management/ or accidental falls/ or accidents, traffic/ or safety.ti,ab. (256 850)
3	program evaluation/ or Education/ or Educational Measurement/ or ed.fs. or questionnaires/ or health education/ or (educat* or train* or teach or intervention* or class or classes or program* or campaign* or skill*).mp. (1968088)
4	1 and 2 and 3 (618)
5	clinical trial/ or cohort studies/ or longitudinal studies/ or follow-up studies/ or prospective studies/ or (case–control studies/ or retrospective studies/ or cross-sectional studies/) or (prognosis/ or disease-free survival/ or medical futility/ or pregnancy outcome/ or treatment outcome/ or treatment failure/) or disease progression/ or (morbidity/ or incidence/ or prevalence/) or (mortality/ or cause of death/ or fatal outcome/ or hospital mortality/ or infant mortality/ or maternal mortality/ or survival rate/) or (survival analysis/ or disease-free survival/) or natural histor.tw. or predictive value of tests/ or (multicenter study.pt. or multicenter studies as topic/) or (randomised controlled trial.pt. or randomised controlled trials as topic/) (2662968)
6	1 and 2 and 5 (723)
7	4 or 6 (1055)
8	limit 7 to "all child (0 to 18 years)" (657)
9	(child* or teen* or adolescen* or youth* or paediatric* or pediatric*).mp. (2404956)
10	7 and 9 (678)
11	8 or 10 (680)

Selection of eligible studies

Studies were included if they met the following 'a priori' criteria: (1) children and youth under 19 years of age; (2) examined a bicycle skills training intervention that included the teaching of practical bicycle handing skills and/or bicycle-specific traffic regulations; (3) objective and quantifiable outcome measure(s) were reported including injury frequency, injury severity, bicycling behaviour, knowledge of bicycle safety and traffic rules, or attitudes towards safe cycling; (4) all study designs were comparing pre/post-training programme or had a comparison group; and (5) original data were reported. There were no restrictions on language when searching the electronic databases. In addition, both peer-reviewed and grey literature were included in the search.

Two reviewers independently reviewed titles and abstracts from the search output. Potentially relevant studies were retrieved and independently reviewed by two reviewers using a standardised inclusion criteria form. Discrepancies were resolved through discussion between the two reviewers and were sent to a third reviewer if necessary. Characteristics of included studies were extracted independently by two reviewers, recorded in tables and were checked by a third reviewer. The following information was extracted: study design, number of participants, participant characteristics, intervention characteristics, outcomes and results (see supplementary table, available online only).

Quality assessment

Methodological quality was assessed using the applicable components of the previously validated Downs and Black quality assessment checklist, which measures quality of reporting, internal and external validity, bias, confounding and power.[11]

Studies were given a quality index score (QIS), based on the Downs and Black checklist.[11] When a question was not applicable, for example, appropriate methods of randomisation in a case–control study, such questions did not contribute to the score. In other words, the denominator for the QIS varied by study design (observational vs randomised trial). The QIS was calculated by summing the scores given for each component, and dividing that score by the total possible points, given the study design (ie, observational studies scored out of a total of 28, randomised controlled trials (RCT) scored out of a total of 32). QIS for each study is presented as a percentage score, along with 95% CI.

Data synthesis

Due to the heterogeneity of study designs and interventions included in the review, a meta-analysis was not conducted. Therefore, a descriptive analysis was performed and the results are summarised in evidence tables.

RESULTS

The search strategy identified 2874 unique records. After reviewing titles and abstracts, 2810 were excluded. An additional 37 records were excluded after conducting a full-text review, a further two records were excluded because the full-text could not be located (attempts to retrieve all studies included contacting authors and corresponding organisations). Finally, 25 studies met the inclusion criteria and were reviewed for study quality (figure 1).

Description of studies

Ten studies were conducted in the USA,[12–21] seven from the UK,[8 22–27] four from Australia,[28–31] two from Canada,[32 33] one from The Netherlands,[34] and one from Sweden.[35] Study designs included seven before-and-after studies,[13 17 19 21 22 27 35] six before-and-after studies with a comparison group,[20 26 29–31 34] five RCT,[12 15 18 32 33] four cross-sectional studies,[16 23–25] one cohort,[8] one retrospective cohort[14] and one case–control study.[28]

Injury

Seven observational studies measured injury frequency or severity as the primary outcome (two cross-sectional, two retrospective cohorts, one before-and-after study with a comparison group, one before-and-after study and one case–control study).[14 16 20 23–25 28] The sources of injury data included self-report,[16 20 23 25] previously validated injury surveillance systems[14 28] and national statistics.[24] The bicycle interventions varied from previous participation in on or off-road bicycle training programmes[16 23–25 28] to prospective on and off-road bicycle safety education programmes.[14 20] The duration of training programmes varied from 8 h of total training[24] to 4 months;[20] however, most studies did not report the duration of training.[14 16 23 28]

Review of these seven studies found no statistically significant intervention effect on frequency of injury. Carlin *et al*[28] examined a ‘Bike Ed’, on and off-road bicycle programme, using a case–control design. Previous participation in the programme did not reduce the risk of bicycle-related injury in subsequent years. In fact, the adjusted OR demonstrated an increase in bicycle-related injury with exposure to the Bike Ed programme (OR ranging from 1.32 to 1.94).[28] Preston[25] showed no significant differences in collision rates, severity or type of collision between those who had passed a cycle proficiency training programme and those who had not. In the group of boys aged 12–16 years who passed the cycle proficiency training and reported a high frequency of cycling, the proportion injured was 12% compared to 15% of boys who had never taken the training course. Among a younger age group (6–10 years), the proportion of injury was identical among children who had and had not taken the course (2%).[25] Durkin *et al*[14] compared the incidence of head trauma after the implementation of the Harlem Hospital Injury Prevention Program (HHIPP). They found a 33% reduction in the rate of injury post-HHIPP compared to the pre-intervention period; however, this was not statistically significant (rate ratio (RR) 0.67, 95% CI 0.22 to 2.03).[14] The remaining studies that examined injury as a primary outcome found no concomitant decrease, or marginal decreases in reported injury with bicycle training programmes.[16 20 23 24] The quality index percentage for the observational studies that included injury as an outcome was 62% (95% CI 50% to 74%).

Behaviour

In total, 13 studies assessed bicycling behaviour.[8 12 13 22 23 26 27 29–31 33–35] There were five before-and-after studies with a comparison group,[26 29–31 34] four before-and-after studies,[13 22 27 35] one cohort,[8] one cross-sectional study[23] and two RCT.[12 33] Ten studies measured the ability to perform cycling manoeuvres correctly on or off-road;[8 12 22 27 29–31 33–35] however, three studies used self-report of bicycling behaviour.[13 23 26] The duration of training varied from 90 min[33] to 4 days,[12] with the majority of interventions employing an 8-h bicycle training programme.

Five of the 11 observational studies found significant improvements in bicycling behaviour post-training.[22 26 27 31 35] For example, the study by Wells *et al*[27] showed a dramatic improvement in performing left turns (the percentage of children making major errors declined from 87% to 27%). This improvement, however, was not sustained, major errors rose to 41% at 7 months.[27] When comparing a road-trained group with a playground-trained group, the road group performed significantly better on all manoeuvres in post-tests 1 and 2.[27] A study by Trotter *et al*[31] found improvements in both cycling behaviour in two training groups, (group A, classroom instruction; group B, on and off-road training with classroom bicycle safety instruction). The range of baseline mean scores of riding performance before training was 39–40 for both groups, with post-test scores ranging from 53 to 60.[31] The quality index percentage for these observational studies was 54% (95% CI 41% to 61%).

Both of the RCT studies found no significant change in bicycling behaviour.[12 33] The study by Macarthur *et al*[33] examined the prevalence of safe cycling behaviours at follow-up in the intervention and control groups: straight line riding (90% vs 88%; p=0.782), coming to a complete stop (90% vs 76%; p=0.225) and shoulder checking (0% vs 2%; p=1.000). In the study by Aaron and Krause[12] the students performed a range of operational skills and signals necessary for safe completion of bicycle manoeuvres. There was no reported difference in the proportion of mistakes made between the intervention and control groups.

Knowledge

Knowledge as an outcome was collected in 16 studies.[8 12 13 15–19 21 22 29 31–35] Six studies used a before-and-after design,[13 17 19 21 22 35] five studies were RCT,[12 15 18 32 33] four studies used a before-and-after study design with a comparison group[16 29 31 34] and one study was a cohort.[8] For all of the studies, knowledge was determined via self-report questionnaire.

Five of the 11 observational studies demonstrated an increase in knowledge post-training compared to pre-training scores.[8 17 19 21 31] For example, a cohort study by Savill *et al*[8] showed that children participating in the training programme scored significantly higher compared to 'untrained' children, post-training programme (t=10.54, p<0.0005; mean score of 8.8 compared to 7.7). The quality index percentage for these observational studies was 54% (95% CI 40% to 62%).

Three of the five RCT studies demonstrated improvements in knowledge of bicycling safety;[15 18 33] for example, in the RCT by Macarthur *et al*[33] trained children were less likely to report riding bicycles on the pavement (RR=0.83, 95% CI 0.70 to 0.99) and were less likely to consider a bicycle has less right to the road than a car at follow-up (RR=0.82, 95% CI 0.70 to 0.95); however, there was no statistical significance on other measures of safe cycling knowledge and attitudes, including signalling at left turns, slowing at stop signs and helmet use. McLaughlin and Glang[18] reported that regardless of gender or grade, the intervention students demonstrated greater gains on six of nine computer-generated knowledge items for observational helmet and safety rules, and eight of 16 computerised hazard discrimination items, compared to controls (eg, observational bicycle helmet items, OR=3.2, 95% CI 1.73 to 5.93, and recognition of a dangerous car, OR=6.9, 95% CI 8.4 to 102.0. Finally, in the study by Groesz[15] the intervention and control groups were asked about bicycle safety awareness and maintenance, and the intervention group demonstrated higher post-scores, compared to the control group ($F_{(1,105)}$=16.5, p<0.01). The quality index percentage of RCT studies that examined change in knowledge was 84% (95% CI 67% to 97%). There was no significant difference in QIS between studies that showed an improvement in knowledge or behaviour (61.4%, 95% CI 48.6% to 74.1%) and studies that did not (57.2%, 95% CI 48.2% to 66.2%).

Attitude

Only two studies measured change in bicycling attitude among youth.[23 33] One study used a cross-sectional design[23] and one was a RCT.[33] Neither study demonstrated any change in attitudes of youth participating in a bicycle training programme. Colwell and Culverwell[23] assessed cycling attitude using a 10 item, five-point scale (from strongly disagree to strongly agree). The results indicated that there was no effect of training (report of previous participation in a cycle training course) on attitudes; however, girls reported significantly safer attitudes than boys ($F_{(1,323)}$=16.54, p<0.001).[23] In the RCT by Macarthur *et al*,[33] there were no statistically significant differences between the intervention and control groups with respect to safe cycling attitudes.

DISCUSSION

Formal bicycle skills and safety training programmes did not lead to a reduction in bicycle-related injuries, an increase in observed safe bicycling behaviour, or self-reported knowledge or attitudes. Overall, none of the interventions identified by this review were demonstrated as being highly effective. Studies of higher quality (RCT) measured surrogate outcomes including behaviour, knowledge and attitudes rather than measuring actual injury rates. Therefore, a gap exists in the literature related to high-quality evidence and injury frequency in the context of bicycle skills training.

Limitations of the interventions

A major limitation of this review was the modest quality of the literature. Many studies demonstrated sources of bias, such as significant loss to follow-up, failure to control for a cluster design, no control of confounders, no a priori power calculations, and most studies did not report the follow-up periods. Studies were highly heterogeneous; for example, knowledge was the most commonly measured outcome; however, this review could not definitively conclude whether bicycle skills and/or safety training resulted in improved bicycle safety knowledge, with eight studies demonstrating an improvement[15 17–19 21 22 31 35] and eight studies demonstrating mixed or null results.[8 12 13 16 29 32–34] Ten of the 25 studies did not control for possible confounders including socioeconomic status, cycling frequency and experience.[12 13 16 17 19 21 22 29 31 34]

With respect to the quality of the interventions, programme content was quite similar; however, duration, specific emphases and targeted age groups varied across programmes. This made it more difficult to generalise and compare results across studies.

Strengths and limitations of this systematic review

There are several strengths of this systematic review. First, two independent reviewers conducted the systematic search of 16 databases. In addition, reference lists from relevant studies were examined along with grey literature searches including government agencies, traffic and road accident research bodies and injury prevention organisations. Collaboration with a research librarian was sought to develop a comprehensive search strategy. There were no restrictions on language of publication, and published and grey literature works were considered, therefore increasing the breadth of studies included. Finally, all studies were critically appraised, measured in terms of quality of reporting internal, external validity, bias, confounding and power of studies using the previously validated Downs and Black checklist.[11] There are, however, limitations of this systematic review. First, only published studies were included, thus increasing the risk of publication bias. Of note, both positive and null effects were noted across included studies. In addition, peer-reviewed and non-peer-reviewed articles and reports were included in the systematic search. The second limitation relates to small sample sizes when comparing the difference in QIS, particularly with RCT (n=5).

Implications of this review on injury prevention

This review has several implications for injury prevention. First, there are are several possibilities why skills training interventions may be ineffective in reducing bicycle-related injury. The first includes the inability of children to transfer learned skills into real life settings. Post-intervention cycling behaviour has not been adequately assessed in the literature; therefore, it is unknown how truly effective an education intervention could be in modifying on-road cycling behaviours. In addition, the age that children are physically or developmentally ready to cycle on the roads should be considered. Research suggests that novice cyclists, namely younger, inexperienced cyclists, lack automatic control and may have difficulty understanding and obeying traffic signs and rules.[9] One study[28] showed an increase in injury after skills training. This may be due to increased exposure to traffic after 'training'; similar unintended consequences have been seen following driver training programmes in older youth.[36–38] A common factor in all studies measuring injury as an outcome is that the children's cycling environment often involves sharing public roads with motor vehicles. This environmental hazard may be a stronger determinant in injury risk than any improvements in behaviour or knowledge from education interventions.

CONCLUSIONS

Over the 30-year period spanning the studies in this review, significant resources have been invested in child bicycle skills training interventions around the world. The content of these interventions has changed little over this time and rigorous scientific evaluation of the outcomes has not been emphasised.

In summary, studies examined in this review were of modest quality and do not provide consistent evidence to demonstrate that bicycle skills training interventions reduce injury frequency, injury severity, or increase behaviour, knowledge or attitudes toward safe cycling.

What this study adds

- There is a paucity of high-quality research in the area of bicycle skills training programmes.
- Studies examined in this review do not provide sufficient evidence to demonstrate that bicycle interventions reduce rates of injury, injury frequency, injury severity, or increasing behaviour or attitudes towards safe cycling.
- There is inconclusive evidence to support that educational cycle interventions increase knowledge of safe cycling.

What is already known on the subject

- The efficacy of bicycle skills training at reducing injury, increasing knowledge, behaviour or attitudes towards safe cycling is unknown.
- It has been hypothesised that bicycle training programmes may reduce the frequency of bicycle-related injuries through increased knowledge of traffic regulations, compliance with bicycle rules and training in bicycle-related skills.

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