Cumulative evidence of helmet effects on bicycle injuries

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Abstract

Background: With widely-used use of bicycles, studies of helmet effects on bicycle injuries were intensively conducted after the problem of bicycle injuries emerged. This study aims to justify whether current evidence is sufficient to manifest the effects of helmets.

Methods We exhaustively searched the articles in the databases of Medline, Scopus, and Embase by the term of (helmet* AND (cycl* OR bicycle* OR bike*)) AND injur* by the time of April 10, 2019. The meta-analysis and SSA (study sequential analysis) were conducted.

Results A total of 55 studies are eligible for meta-analysis. The OR (odds ratio) of helmet effect on head injuries compared with other injuries is 0.50 (0.43, 0.59) and effect of helmets on serious head injuries compared with other injuries are protective with OR of 0.34 (0.28, 0.43). Compared with control injuries, the OR of helmet effect on facial injuries is 0.63 (0.45, 0.88). Helmets is not associated with protective effects of neck injuries and OR is 0.98 (0.82, 1.17). SSA results of head injuries, serious head injuries, and face injuries showed, the cumulative Z-curve crossed both the conventional and the trial sequential monitoring boundary. SSA results of neck injuries showed the cumulative Z-curve does not cross both the conventional and the trial sequential monitoring boundary.

Conclusions The helmet has protection effects on head injuries, serious head injuries, and face injuries. The SSA showed the current evidence was sufficient to support the results. More studies of helmet promotion are warranted in the future. Key words: helmet; bicycle injuries; head injuries; face injuries

Background

Bicycle is widely used for traffic, sports, and entertainment purposes. It is reported two million bicycles are used currently worldwide and the number will elevate to five million by 2050. Meanwhile, the concomitant bicycle-related injuries have become a global public health concern. In the US, bicycle usage conferred 1000 deaths and 467000 injuries in the latest report in 2015. China, with the largest number of bicycle users, had more than 2.5 million injuries and 50000 fatalities related to bicycles from 2004 to 2010. In Netherland where the per capital bicycle ownership is as
high as 1,456 bicycle-related injuries per 100 thousand were reported in 2012.4

To prevent bicycle-related injuries, helmet wearing is considered an effective measure. Research has been conducted to investigate its protective effects on various injury types including head, brain, face, and neck injuries. In 1989, Thompson et al. conducted a case-control study, reporting that helmets reduced 85% of head injury risk and 88% of brain injury risk.5 In 2000, Thompson et al. initiated the first systematic review of helmet effects with inclusion of only prospective studies and medical certificates of injuries, and found that the risk reduction provided by helmets on head, brain, and severe brain injuries ranged from 63–88%.6 The first meta-analysis including 16 studies by Attewell et al. in 2001 showed that helmets reduced the risk of head injury, brain injury, facial injury, and fatal injury by 60%, 58%, 47%, and 73%.7

Later, Elvik et al. re-analyzed the work of Attewell et al. through evaluating publication by trim-and-fill method, estimating time trend bias, correcting the zero-count cell, and updating the meta-analysis with new publications in 2011. 8, 9 With the concerns of usage of trim-and-fill method and the heterogeneity of different injuries which should be evaluated separately, Olivier et al. performed a meta-analysis including 40 studies in order to take into account sources of bias in 2017. It is found the efficacy of helmets reduce the risk of head injury by 51%, of serious head injury by 69%, of fatal head injury by 65%, and of face injury by 33%. The evidence did not support the helmet protection effects on neck injury.10 Høye et al replicated the results of previous studies with inclusion of newly published data in 2018. The article investigated multiple confounding variables such as influence of alcohol, cyclists’ age, and speed limit.11 It also analyzed the influence of data resources and the moderators such a helmet usage rate and crash type. The helmet effects of reduction of head injuries and face injuries are 48% and 23%, respectively, which showed significant effects. The reduction of neck injuries was not statistically significant.

Though the helmet protection effects on head, brain, and face injuries are conclusive, it is unclear that whether the evidence is sufficient to support current effects of helmet in the addition of new publications and whether we should draw more attention from manifesting effects of helmets on other
aspects to improve bicycle safety.8, 9 With the questions for previous literature gap, this meta-analysis aimed to evaluate the effects of helmet on risk of bicycle injuries, and explore whether the evidence of current studies are sufficient and conclusive to support the effects of helmets.

Methods
The checklist PRISMA for systematic reviews and meta-analysis was followed during the process of implementation and report. The protocol was registered in Prospero (www.crd.york.ac.uk/PROSPERO/, ID: CRD42019131751).

Study Eligibility, Search Strategy, And Selection Criteria
The study inclusion criteria were as the following: the studies evaluated or compared bicycle-related injuries; the studies reporting individual cyclists’ injuries of head, brain, face, and neck with medical diagnosis (studies with self-report injuries were excluded); the studies with details to complete 2 × 2 table of injury comparison by presence or absence of helmet; and studies were English language publications in peer review journals. Three electronic databases (Medline, Scopus, and Embase) were exhaustively searched for the articles and reports on April 10, 2019. Previous review article references were served as an additional source. Search terms were used (helmet* AND (cycl* OR bicycle* OR bicycle*)) AND injur*, to include as many studies as it could. Only the articles published in English were included. Two authors independently reviewed the titles and abstracts of the obtained studies and made first evaluation of inclusion or exclusion. Next, the studies with discrepancies at the first step were retrieved with full-text review in order to judge whether they met eligibility criteria. Disagreements between the two authors were resolved through discussion with the third author.

Figure 1 presents the study selection process. One author gleaned information (PMID, author name, country, study design, sample size, 2 × 2 table of injuries of different parts, the ORs if provided, the type of helmet, and other risk behavior factors) from the included articles and summary the information into Table 1. A second author checked the quality and accuracy of the data.

| Study | PubmedID | Data Years | Published years | Country | Data source | Helmet law | Wearing rate | Wearing rate | Age categories | Sample size | Newcastle-Ottawa Scale total |
|-------|----------|------------|----------------|---------|-------------|------------|--------------|--------------|----------------|-------------|-----------------------------|

Table 1
Characteristics of included studies.
| Authors                   | Year(s)   | Country 1 | Country 2 | Study Type | Location | Primary Care? | Follow-up | Score |
|--------------------------|-----------|-----------|-----------|------------|----------|---------------|-----------|-------|
| Thompson et al.          | 1986-1987 | USA       | Hospital  | No         | Low      | All           | 668       | 8     |
| Thompson et al.          | 1986-1987 | USA       | Hospital  | No         | Low      | All           | 531       | 8     |
| Spaite et al.            | 1986-1987 | USA       | Hospital  | No         | Low      | All           | 284       | 7     |
| McDermott et al.         | 1987-1989 | Australia | Hospital  | No         | Low      | All           | 1710      | 5     |
| Mainaru et al.           | 1992-1994 | UK        | ED/Polic  | No         | Low      | All           | 1042      | 5     |
| Thomas et al.            | 1991-1992 | Australia | Hospital  | Yes        | Medium   | Child         | 403       | 6     |
| Thompson et al.          | 1992-1994 | USA       | ED/Polic  | No         | Medium   | All           | 3390      | 7     |
| Li et al.                | 1989-1992 | Canada    | Hospital  | No         | Low      | Child         | 1538      | 5     |
| Finvers et al.           | 1991-1993 | Canada    | Hospital  | No         | Low      | Child         | 699       | 5     |
| Jacobson et al.          | 1991-1995 | Australia | Hospital  | Yes        | Medium-High | All         | 229       | 5     |
| Linn et al.              | 1991-1995 | Canada    | Hospital  | No         | Low      | Child         | 1462      | 3     |
| Shafi et al.             | 1993-1995 | USA       | Hospital  | Partially  | Low      | Child         | 208       | 3     |
| Thompson et al.          | 1992-1994 | USA       | ED/Polic  | No         | Medium   | All           | 3388      | 7     |
| Borglund et al.          | 1995-1998 | USA       | Hospital  | Partially  | Low      | Child         | 125       | 3     |
| Hansen et al.            | 2001-2002 | Norway    | ED/Polic  | No         | Low      | All           | 991       | 7     |
| Heng et al.              | 2004-2005 | Singapore | Hospital  | No         | Low      | All           | 160       | 3     |
| Airaksinen et al.        | 2004-2006 | Finland   | ED/Polic  | No         | Low      | All           | 151       | 4     |
| Sze et al.               | 2004-2006 | Hong Kong | Hospital  | No         | Low      | All           | 682       | 4     |
| Dinh et al.              | 2008-2010 | Australia | Hospital  | Yes        | High     | Adult         | 287       | 5     |
| Amoros et al.            | 1998-2008 | France    | Hospital  | No         | Medium   | All           | 8373      | 6     |
| Crocker et al.           | 2006-2009 | USA       | Hospital  | No         | Medium   | Adult         | 420       | 3     |
| Wagner et al.            | 2008-2010 | USA       | Hospital  | No         | High     | Adult         | 163       | 3     |
| Bambach et al.           | 2001-2009 | Australia | Hospital  | Yes        | High     | All           | 6745      | 5     |
| Dinh et al.              | 2008-2009 | Australia | Hospital  | Yes        | High     | Adult         | 110       | 5     |
| McIntosh et al.          | 2008-2009 | Australia | Hospital  | Yes        | High     | All           | 137       | 5     |
| Webman et al.            | 2008-2011 | USA       | Hospital  | Partially  | Medium   | All           | 374       | 5     |
| Lindsay & Brusson       | 2008-2009 | Canada    | ED/Polic  | Partially  | High     | Child         | 15569     | 3     |
| Malczyk et al.           | 2012-2013 | Germany   | Hospital  | No         | Low      | All           | 543       | 3     |
| Otte & Wiese             | 2000-2011 | Germany   | ED/Polic  | No         | Low      | All           | 4245      | 3     |
| Zibung et al.            | 2010-2012 | Sweden    | Hospital  | No         | Medium   | Adult         | 186       | 4     |
| Dinh et al.              | 2012-2014 | Australia | Hospital  | Yes        | High     | Adult         | 254       | 3     |
| Gulack et al.            | 2007-2011 | USA       | Hospital  | Partially  | Low      | Child         | 7678      | 3     |
| Harada et al.            | 2002-2011 | USA       | Hospital  | Partially  | Medium   | All           | 505       | 3     |
| Kaushik et al.           | 2002-2011 | USA       | ED/Polic  | No         | Low      | Child         | 567       | 3     |
| Sethi et al.             | 2012-2015 | USA       | Hospital  | Partially  | Medium   | All           | 699       | 4     |
| Study Authors | Year Range | Nationality | Location | Helmet Requirement | Injury Incidence | Injured Type | Sample Size |
|---------------|------------|-------------|----------|--------------------|-----------------|--------------|-------------|
| Sethi et al.  | 2012-2014  | USA         | Hospital | Yes                | 8.40%           | Low          | 371         |
| Bergens et al.| 2003-2012  | Sweden      | Hospital | No                 | 6.40%           | Medium       | 2250        |
| Juhr et al.   | 2012-2014  | Sweden      | Hospital | No                 | 14.90%          | Low          | 242         |
| Rizzi et al.  | 2012-2014  | Sweden      | Hospital | No                 | 33.10%          | Medium       | 55220       |
| Orsi et al.   | 2012-2014  | USA         | Hospital | No                 | 25.10%          | Medium       | 6267        |
| Olivier et al.| 2012-2014  | Australia   | ED/Polic | Partially          | 76%             | High         | 6745        |
| Phillips et al.| 2012-2014 | USA         | Hospital | Partially          | 21%             | Low          | 16681       |
| Wall et al.   | 2012-2014  | USA         | Hospital | No                 | 33.30%          | Medium       | 825         |
| Helak et al.  | 2012-2014  | USA         | ED/Polic | Partially          | 20.60%          | Low          | 9174        |
| Kuo et al.    | 2012-2014  | Taiwan      | Hospital | No                 | 10.60%          | Low          | 812         |
| Cooke et al.  | 1984-1992  | Australia   | Hospital | No                 | 20%             | Low          | 64          |
| Rivara et al. | 1992-1994  | USA         | ED/Polic | No                 | 51%             | High         | 3384        |
| Persaud et al.| 2006-2010  | Canada      | Hospital | Partially          | 26.40%          | Medium       | 129         |
| Hooten et al. | 2005-2010  | USA         | Hospital | Partially          | 18.90%          | Low          | 249         |
| Bande et al.  | 2009-2014  | Germany     | Hospital | No                 | 25%             | Medium       | 55          |
| Benjami et al.| 2010-2014  | USA         | Hospital | No                 | 36%             | Medium       | 85187       |
| McAdams et al.| 2006-2015  | USA         | ED       | Partially          | 27.20%          | Medium       | 66897       |
| Stier et al.  | 1999-2015  | Germany     | Research Institute | Not mentioned | 11.80%          | Low          | 7004        |
| Harvey et al. | 1999-2015  | USA         | ED       | Partially          | 50%             | High         | 417         |

**Data Analysis And Data Synthesis**

The Newcastle-Ottawa Scales (NOS) were used to assess the potential bias for observational studies about helmet effects on injuries by two independent authors. The two authors implemented ratings of NOS scores and then compared. Discrepancies between the two authors were re-evaluated through discussion involving a third author if necessary. The collected ORs or calculated ORs based on 2 × 2 table of injury for helmeted versus unhelmeted cyclists were pooled by random model. Subgroup analyses were conducted. The process was conducted through Stata (Version 11.0, Stata Corp., College Station, TX, USA). Heterogeneity was evaluated by the parameter of \( I^2 \). Publication bias was assessed using funnel plots visually and assessed by Begg’s test.

**Study Sequential Analysis**

Study sequential analysis (SSA) was conducted to determine whether the sample size included in the
meta-analysis was sufficient for manifesting the effect size of helmets. For the SSA, when the Z-curve crosses the conventional boundary, a significant difference is considered which means the effect size of helmets is significant. Moreover, if the Z-curve passes through the trial sequential monitoring boundary or required information size (RIS) boundary, it indicates the evidence of meta-analysis is sufficient and conclusive to support the effect size of helmets. Otherwise, the evidence is rendered inconclusive and more studies were warranted to verify the effect size.

Results
The flow chart for literature selection process is shown in Fig. 1. The literature search gleaned 1880 results in total with deletion of 1703 duplicates. After screening the titles and abstracts, 1795 records were eliminated and the remained 85 records were further evaluated under full-text review based on the eligibility criteria. A total of 34 studies did not meet the criteria in which five were included in previous meta-analysis. With reference to previous meta-analyses, four studies were added to the studies for quantitative synthesis. In total, there were 55 studies eligible for quantitative synthesis. The 55 studies have the sample size as large as 330,200.

The characteristics of studies included in this meta-analysis are shown in Table 1. The included studies were conducted from 1986–2005 including 12 countries and regions (Asia12–14: 3,Australia10, 15–23Europe24–36North America5, 6, 37–63North America). The injury data from included studies were collected in different settingsemergency room39, 62, 63 (n = 3), emergency room and police database6, 10, 17, 24–26, 29, 31, 38, 41, 42, 48, 51, 57, 58 (n = 15)hospital (n = 34)hospital and emergency room5, 37 (n = 2)and research institute36 (n = 1). The number of studies reported the data about children,16, 31, 35, 40–44, 48, 49, 51, 53, 55, 62 adults,18–20, 30, 45, 46, 61 and all ages are 14, 7, and 32, respectively. The mandatory helmet laws were implemented as background of 10 studies mainly in Australia.16–23, 53, 64 The countries or regions partially implemented helmet law in 13 studies.43, 44, 47–50, 52, 55, 57, 59, 60, 62, 63 The helmet use rate is low (< 25%) in 26 studies while in 9 studies the helmet use rate is high (> 50%). There were 35 studies reporting head injuries, 36 studies investigating serious head injuries, 27 studies concerning facial injuries, and only 17 studies with
evaluation of helmet effects on neck injuries. The NOS scores ranged from 3 to 8 (the full score is 9), and the average NOS score of all studies is 4.3.

The odds ratio of helmet effect on head injuries compared with other injuries are 0.50 [95% Confidence Interval (CI): 0.43, 0.59] and $I^2$ is 90% while OR of helmet effect on serious head injuries compared with other injuries are 0.34 (95% CI: 0.28, 0.43) and $I^2$ is 72.2%. Compared with control injuries, the OR of helmet effect on facial injuries is 0.63 (95% CI: 0.45, 0.88) and $I^2$ is 98.7%. For the neck injuries, the OR of helmet effect is 0.98 (95% CI: 0.82, 1.17) and $I^2$ is 35.8%. The results of meta-analyses are illustrated in Table 2, Fig. 2, Supplementary Fig. 1, Supplementary Fig. 2, and Supplementary Fig. 3.

### Table 2
Results of meta-analysis.

|                  | Head injuries OR | I square | Serious head injuries OR | I square | Face injuries OR | I square | Neck injuries OR | I square |
|------------------|------------------|----------|--------------------------|----------|------------------|----------|------------------|---------|
| Overall          | 0.50 (0.43, 0.59) | 92.90%   | 0.34 (0.28, 0.43)        | 90.40%   | 0.63 (0.45, 0.83) | 98.60%   | 0.98 (0.82, 1.17) | 35.80%  |
| Helmet wearing rate |                  |          |                          |          |                  |          |                  |         |
| low              | 0.38 (0.31, 0.48) | 54.70%   | 0.26 (0.15, 0.46)        | 90.20%   | 0.48 (0.29, 0.80) | 65.40%   | 0.86 (0.64, 1.16) | 0       |
| medium           | 0.53 (0.44, 0.65) | 69.60%   | 0.37 (0.27, 0.51)        | 90.20%   | 0.76 (0.59, 0.98) | 68.40%   | 1.00 (0.76, 1.31) | 27.70%  |
| high             | 0.54 (0.43, 0.67) | 93.60%   | 0.40 (0.31, 0.52)        | 64.70%   | 0.61 (0.32, 1.15) | 99.50%   | 1.03 (0.66, 1.62) | 53.50%  |
| Legislation status |                  |          |                          |          |                  |          |                  |         |
| no               | 0.52 (0.42, 0.64) | 91.40%   | 0.40 (0.32, 0.50)        | 64.40%   | 0.62 (0.37, 1.03) | 99.10%   | 1.03 (0.81, 1.30) | 52%     |
| partially        | 0.49 (0.37, 0.65) | 90.60%   | 0.37 (0.24, 0.59)        | 96%      | 0.70 (0.43, 1.14) | 96.10%   | 0.88 (0.67, 1.16) | 0       |
| yes              | 0.44 (0.33, 0.60) | 51.80%   | 0.21 (0.13, 0.33)        | 77.20%   | 0.65 (0.31, 1.37) | 71.40%   | -                | -       |

OR = odds ratio. The odds ratio of helmet effects on different kinds of bicycle injuries.

The ORs of helmet effects on head injuries in low, medium, and high wearing rate groups were 0.38 (95% CI: 0.31, 0.48), 0.53 (95% CI: 0.44, 0.65), and 0.54 (95% CI: 0.43, 0.67), respectively. The ORs of helmet effects on head injuries in the situations without mandatory legislation, with partial legislation, with legislation were 0.52 (95% CI: 0.42, 0.64), 0.49 (95% CI: 0.37, 0.65), and 0.44 (95% CI: 0.33, 0.60). The ORs of helmet effects on serious head injuries in low, medium, and high wearing rate groups were 0.26 (95% CI: 0.15, 0.46), 0.37 (95% CI: 0.27, 0.51), and 0.40 (95% CI: 0.31, 0.52),
respectively. The ORs of helmet effects on serious head injuries in the situations without mandatory legislation, with partial legislation, with legislation were 0·40 (95% CI: 0·32, 0·50), 0·37 (95% CI: 0·24, 0·59), and 0·21 (95% CI: 0·13, 0·33). In low, medium, and high helmet wearing rate groups, the ORs of helmet effects on face injuries were 0·48 (95% CI: 0·29, 0·80), 0·76 (95% CI: 0·59, 0·98), and 0·61 (95% CI: 0·32, 1·15), respectively. The ORs of helmet effects on face injuries in the different mandatory helmet legislation status from absence to presence were 0·62 (95% CI: 0·37, 1·03), 0·70 (95% CI: 0·43, 1·14), and 0·65 (95% CI: 0·31, 1·37). From low helmet wearing rate to high, the ORs of helmet effects on neck injuries were 0.86 (95% CI: 0.64, 1.16), 1·00 (95% CI: 0·76, 1·31), and 1·03 (95% CI: 0·66, 1·62), respectively. The ORs of helmet effect on neck injuries were only available under the circumstance without mandatory helmet and with partial legislation, which are 1·03 (95% CI: 0·81, 1·30) and 0·88 (95% CI: 0·67, 1·16), respectively. There was no strong evidence of publication bias in the four meta-analyses and the funnel plots showed symmetry of the four meta-analyses. The sensitivity analysis showed the results are stable after withdraw of a single study.

SSA results of head injuries showed, the cumulative Z-curve crossed both the conventional and the trial sequential monitoring boundary. SSA results of serious head injuries indicated, cumulative Z-curve crossed both the conventional and the trial sequential monitoring boundary as well. Cumulative Z-curve in the SSA results of face injuries also crossed both the conventional and the trial sequential monitoring boundary. SSA results of neck injuries showed the cumulative Z-curve does not cross both the conventional and the trial sequential monitoring boundary. The results are illustrated in Fig. 3, Supplementary Fig. 4, Supplementary Fig. 5, and Supplementary Fig. 6.

Discussion

This is an updated meta-analysis investigating helmet effects on bicycle-related injuries, with six additional studies compared with Hoya’s work of 2018. We also conducted SSA to justify whether the evidence of helmet effects are conclusive and sufficient for the first time. Previous meta-analysis supported the protection effects of helmets on head injuries, serious head injuries, face injuries while the protection effects on neck injuries are not significant.6–11

The results of meta-analyses further confirmed the protection effect of helmets on the head injuries,
The results of helmets on neck injuries did not show a significant protection effect which is also consistent with previous studies.\textsuperscript{10, 11} Compared with previous meta-analyses, we implemented SSA in this meta-analysis and showed the sufficient and conclusive evidence of helmet effect on bicycle injuries. The results indicated the current evidence is sufficient to support the helmet effect. The researchers could exert more efforts to investigate the effects in other details. For neck injuries, the results showed the helmet did not have protection effects, which was also consistent with previous results.\textsuperscript{10, 11} In the SSA analysis of neck injuries, the evidence is sufficient to support the non-significant effects of helmets.

In our study, we also conducted subgroup analysis about the helmet effects under different legislation status and different helmet wearing rates. The heterogeneity did not decrease after subgroup analysis. The source of heterogeneity could be the selection of controls which are undefined other kinds of injuries rather than the use status of helmet. For the head injuries and serious head injuries, in different situations of helmet wearing rates and mandatory helmet legislation, the protection effects remain significant. For these two types of injuries, with the increase of helmet wearing rate, the effect sizes of helmet protection consistently increase. From the situation of legislation absence to mandatory legislation, the effect sizes of helmet protection decrease. Currently, we could not confirm the association between helmet use status and effect size of helmet protection and we could not observe the similar situation in face injuries and neck injuries. However, future studies could further investigate whether helmet wearing rate and legislation will influence helmet protection effect size and the underlying mechanisms. Moreover, in subgroup analysis, we also conducted SSA analysis which indicated the evidence was sufficient to support the results in subgroup analysis.

Other factors will also influence the effects of helmets such the texture of the helmets. It is reported that the soft texture and hard texture of helmets may have different effects in protection. The specific design of the helmet such as chin bar will also influence the function.\textsuperscript{65} The magnitude of protection effects of hard helmets is larger than that of soft helmets, even some studies showed soft helmets may increase the incidence of neck injuries.\textsuperscript{8} However, the application of soft helmets become more
and more widely. Other studies believed the variation in the effects of soft helmets and hard helmets is because of different definitions of injuries in different meta-analysis. The subgroups of helmets and relevant applications should be investigated in the future. However, the studies pooled into the meta-analysis have some limitations. First, the definitions of control groups are not clear which come from the other injuries. The type of other injuries may vary in different scenarios, which enhance the heterogeneity. Future case-control study could try to arrange the people riding with helmets and without helmets into case group and control group, respectively. Second, according to the NOS scores, the qualities of most of case-control studies are not high because they did not clarify the definition of the controls, the controlled factors for comparability, and the ascertainment method of controls. The more precise criteria for controls are warranted in the future. Moreover, the underlying reasons of why bicyclists did not wear helmets have not been investigated in the included studies. Future exploration about the bicyclists’ motivations should be evaluated on the basis of helmet effect studies.

Conclusions
In conclusion, the evidence is sufficient to support meta-analysis results of the protective effects of helmets on head injuries and serious head injuries, and face injuries, and show the null effects on neck injuries. Future researches could pay more attention to the improvement of helmet usage.

Abbreviations
SSA  Study sequential analysis
RIS  required information size

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Availability of data and materials
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

**Competing interests**

The authors declare that they have no competing interests.

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None.

**Authors’ contributions**

All authors have read and approved the manuscript. SC was responsible for conceptualisation and project management, search design and execution. GL and SO supervised the study. SC, HC, MT, YW, YB, and MZ were responsible for screening, data extraction, quality assessment and interpretation. SC prepared the first draft. GL, DG, XW, BS, and ZY were responsible for revisions and approval to submit manuscript.

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Figures
Figure 1

Flow chart. The process of literature search and study inclusion/exclusion. A total of 1880 studies were screened and 55 studies were included for analysis.
Figure 2

Forest plot of helmet effects on head injuries. The odds ratio of helmet effect on head injuries.

Study ID | OR (95% CI) | Weight (%) |
--- | --- | --- |
Thompson et al. 1989 | 0.25 (0.15, 0.43) | 2.94 |
McDermott et al. 1993 | 0.50 (0.36, 0.69) | 3.78 |
Thomas et al. 1994 | 0.51 (0.32, 0.84) | 3.13 |
Thompson et al. 1996 | 0.30 (0.24, 0.36) | 4.18 |
Jacobson et al. 1998 | 0.37 (0.20, 0.70) | 2.60 |
Linn et al. 1998 | 0.64 (0.49, 0.83) | 3.97 |
Shafi et al. 1998 | 1.37 (0.61, 3.09) | 2.06 |
Borglund et al. 1999 | 0.68 (0.25, 1.84) | 1.61 |
Hansen et al. 2003 | 0.50 (0.33, 0.77) | 3.37 |
Heng et al. 2006 | 0.09 (0.01, 0.73) | 0.53 |
Airaksinnen et al. 2010 | 0.31 (0.12, 0.81) | 1.68 |
Sze et al. 2011 | 0.98 (0.33, 2.98) | 1.41 |
Amoros et al. 2012 | 0.78 (0.67, 0.90) | 4.29 |
Bergenstal et al. 2012 | 1.57 (0.68, 3.61) | 2.00 |
Crocker et al. 2012 | 0.51 (0.33, 0.79) | 3.31 |
Wagner et al. 2012 | 1.50 (0.50, 4.48) | 1.43 |
Bambach et al. 2013 | 0.41 (0.35, 0.49) | 4.24 |
Dinh et al. 2013 | 0.23 (0.09, 0.57) | 1.76 |
Mclbtosh et al. 2013 | 0.35 (0.17, 0.72) | 2.33 |
Rizzi et al. 2013 | 0.43 (0.34, 0.55) | 4.03 |
Webman et al. 2013 | 0.79 (0.46, 1.36) | 2.93 |
Lindsay & Brussoni, 2014 | 0.39 (0.36, 0.43) | 4.38 |
Malczyk et al. 2014 | 1.10 (0.67, 1.81) | 3.09 |
Orsi et al. 2014 | 0.42 (0.19, 0.94) | 2.09 |
Otte & Wiese, 2014 | 0.62 (0.47, 0.81) | 3.93 |
Zibung et al. 2014 | 0.57 (0.28, 1.15) | 2.35 |
Dinh et al. 2015 | 0.39 (0.20, 0.76) | 2.49 |
Gulack et al. 2015 | 0.45 (0.40, 0.51) | 4.34 |
Kaushik et al. 2015 | 0.26 (0.15, 0.45) | 2.87 |
Sethi et al. 2015 | 0.22 (0.10, 0.47) | 2.16 |
Olofsson et al. 2015 | 0.50 (0.42, 0.60) | 4.21 |
Harvey et al. 2017 | 0.12 (0.05, 0.32) | 1.70 |
Benjamin et al. 2018 | 0.82 (0.79, 0.86) | 4.44 |
McAdams et al. 2018 | 0.66 (0.59, 0.73) | 4.38 |
Overall | **0.50 (0.43, 0.58)** | 100 |

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injuries compared with other injuries are 0.50 (95% CI: 0.43, 0.59).

Figure 3

SSA results of helmet effects on head injuries. The cumulative Z-curve crossed both the conventional and the trial sequential monitoring boundary.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

Supplementary Figure 2. Forest plot of face injuries.pdf
Supplementary Figure 6. SSA neck injuries.pdf
Supplementary Figure 3. Forest plot of neck injuries.pdf
Supplementary Figure 4. SSA serious head injuries.pdf
Supplementary Figure 5. SSA face injuries.pdf
Supplementary Table 1. Newcastle-Ottawa Scale score.docx
Supplementary Figure 1. Forest plot of serious head injuries.pdf