Cumulative evidence of helmet effects on bicycle injuries

Siyu Chen
First Affiliated Hospital, Army Medical University
Shan Ou
Chengdu First People's Hospital
Huijie Cui
First Affiliated Hospital, Army Medical University
Mingshuang Tang
First Affiliated Hospital, Army Medical University
Yutong Wang
First Affiliated Hospital, Army Medical University
Min Zhang
First Affiliated Hospital, Army Medical University
Ye Bai
First Affiliated Hospital, Army Medical University
Bing Song
First Affiliated Hospital, Army Medical University
Dongqing Gu
First Affiliated Hospital, Army Medical University
Xin Wang
First Affiliated Hospital, Army Medical University
Zhiyong Yin
Daping Hospital, Army Medical University
Guodong Liu (frankliugd@163.com)
Daping Hospital, Army Medical University

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Abstract

Background: With the wide 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 support 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. The protocol was registered in Prospero (www.crd.york.ac.uk/PROSPERO/, ID: CRD42019131751).

Results: A total of 55 studies were eligible for meta-analysis. The OR (odds ratio) of helmet effect on head injuries compared with other injuries was 0·50 (0·43, 0·59) and effects of helmets on serious head injuries compared with other injuries were protective with an OR of 0·34 (0·28, 0·43). Compared with control injuries, the OR of helmets' effects on facial injuries is 0·63 (0·45, 0·88). Helmets were not associated with protective effects with regards to neck injuries and the OR was 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.

Background

Bicycles are widely used for transportation, sports, and entertainment purposes. It is reported two million bicycles are used currently worldwide, and the number will elevate to five million by 2050.[1] Meanwhile, concomitant bicycle-related injuries have become a global public health concern. In the US, bicycle usage conferred 1,000 deaths and 467,000 injuries in the latest report in 2015.[2] China, with the largest number of bicycle users, had more than 2.5 million injuries and 50,000 fatalities related to bicycles from 2004 to 2010.[3] In the Netherlands, where per capital bicycle ownership is as high as one which is the highest in the world, 456 bicycle-related injuries per 100 thousand people were reported in 2012.[4]

Helmet wearing is considered an effective measure to prevent bicycle-related injuries. Research has been conducted to investigate its protective effects on various injury types including head, brain, face, and neck injuries taking other kinds of injuries as controls. 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 the 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% to 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 as 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 whether the evidence is sufficient to support current effects of helmet on the basis of all the current studies and whether we should refer to the evidence and come up with effective measures to improve bicycle safety.[8], [9] Though meta-analysis could show summarized results with pooling different studies, without adequate evaluation it is difficult to know whether the merged results in meta-analysis and the accrued sample size of the whole meta-analysis is sufficient to support the combined results and whether we should continue to do individual studies to add power to the previous meta-analysis.[12] With the questions from gaps in the previous literature, this meta-analysis aimed to evaluate the effects of helmet on the risk of bicycle injuries, and explore whether the evidence of current studies are sufficient and conclusive to support the effects of helmets. If we could justify that current studies are sufficient to support the effects of helmets on different injuries respectively, it would be beneficial to take advantage of the evidence and develop helmet promotion strategies in the future.

Methods

The checklist PRISMA for systematic reviews and meta-analysis was followed during the process of implementation and reporting.[13] 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 follows：the studies evaluated or compared bicycle-related injuries; the studies reported 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 showing the numbers of wearing helmets or not and the numbers with injuries and without injuries; and studies were English language publications in peer reviewed journals. Three electronic databases (Medline, Scopus, and Embase) were exhaustively searched for the articles and reports on April 10, 2019 without a publication time limit. The search of references of previous review articles and included studies served as an additional source to identify potential studies which met inclusion criteria. Search terms were used (helmet* AND (cycl* OR bicycle* OR bicycle*)) AND injur*, in all fields, to include as many studies as possible. Only the articles published in English were included. Two authors independently reviewed the titles and abstracts of the obtained studies and made the 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 summarized the information into Table 1. A second author checked the quality and accuracy of the data.

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.[14] 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 un-helmeted cyclists were pooled by random model. Subgroup analyses were conducted to show whether different helmet wearing rates and helmet legislation status will influence the effects of helmets. The first subgroup analysis was to show the helmet effects under different helmet wearing rates, which are low (< 25%), medium (25%-50%)and high (>50%), respectively. The second subgroup analysis was to demonstrate the helmet effects under different helmet wearing legislation status. There were three statuses as following: absence of legislation, legislation which was conducted partially, and legislation which was conducted fully. 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.[15] Sensitivity analysis was conducted to show whether withdrawing one single study will largely influence the pooled results.[16, 17]

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. To reduce the chance of overall type I error (false positive error) in a single study, evaluating boundaries can be conducted to assess whether a single study could be paused early because the P value is sufficiently small. Because no evidence supports why the standards for a meta-analysis should be less strict than those for a single study, analogous study (compared to a single study) which monitors boundaries can be conducted in meta-analysis as SSA. The underlying assumption for SSA is that significance testing and calculation of the 95% confidence intervals are conducted every time when a new study is added. SSA depends on the quantity of required information size. It can show to what extent of information size the results could surpass the boundary of significance.[12, 18, 19] 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. Stata (Version 11.0, Stata Corp., College Station, TX, USA) was used to conduct SSA.

Results

The flow chart for literature selection process is shown in Figure 1. A total of 1,880 unique abstracts were identified through searching. Of these 85 were reviewed in full text, 55 of which were included in this review. 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 which were all case-control 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 to 2015, including 12 countries and regions (Asia[20-22]（3）Australia[10, 23-31]（10）Europe[32-44]（13）North America[5, 6, 45-71]（29). The injury data from included studies were collected in different settings: emergency room (n = 3), emergency room and police database (n = 15)，hospital (n = 34)，hospital and emergency room (n = 2)，and research institute (n = 1). The number of studies reported the data about children, adults, and all ages are 14, 7, and 32, respectively. The mandatory helmet laws were implemented as background of 10 studies mainly in Australia. The countries or regions partially implemented helmet laws in 13 studies. The helmet use rate was low (<25%) in 26 studies while in 9 studies the helmet use rate was 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 number of studies scored with 3, 4, 5, 6, 7, and 8 were 24, 10, 12, 2, 5, and 2, respectively.

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 the I^2 is 92.9% while the OR of helmet effect on serious head injuries compared with other injuries was 0·34 (95% CI: 0·28, 0·43) and the I^2 was 90.4%. Compared with control injuries, the OR of helmet effect on facial injuries was 0·63 (95% CI: 0·45, 0·88) and the I^2 was 98.6%. For neck injuries, the OR of helmet effect was 0·98 (95% CI: 0·82, 1·17) and the I^2 was 35.8%. The results of meta-analyses are illustrated in Table 2 and Figure 2. The results of Begg’s test in head injuries, serious head injuries, face injuries, and neck injuries are Pr > |z| = 0·258, 0·942, 0·657, and 0·443, respectively, which are all larger than 0·05. And the Begg's plots showed symmetry of the included studies.

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 were 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 were 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 Figure 3, Supplementary Figure 4, Supplementary Figure 5, and Supplementary Figure 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 were not significant.[6-11]

The results of meta-analyses further confirmed the protection effect of helmets on head injuries, face injuries, and serious head injuries.[10], [11] The results of helmets on neck injuries did not show a significant protection effect, which is also consistent with previous studies.[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.[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 helmets. For 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 circumstances, which are no legislation, the status with partial legislation, to the condition with full mandatory legislation, the effect sizes of helmet protection decreases. Currently, we can not confirm the association between helmet use status and effect size of helmet protection and we can 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 soft tand hard texture of helmets may have different effects in protection.[8] The specific design of the helmet, such as the inclusion of a chin bar, will also influence the function.[69] The magnitude of protection effects of hard helmets is larger than that of soft helmets, and some studies showed soft helmets may increase the incidence of neck injuries.[8] However, the use of soft helmets is becoming wider.[72] Other studies showed that the variation in the effects of soft helmets and hard helmets is because of different definitions of injuries in different meta-analysis.[35] 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 in which come from other injuries. The type of other injuries may vary in different scenarios, which enhance heterogeneity. Future case-control studies 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 quality of most of case-control studies are not high because they do not clarify the definition of the controls, the controlled factors for comparability, and the ascertainment method of controls. 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 research could pay more attention to the improvement of helmet usage.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analyzed 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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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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Abbreviations

SSA Study sequential analysis

RIS required information size

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Tables

Table 1. Characteristics of included studies.

Study	PubmedID	Data Years	Published years	Country	Data source	Helmet law	Wearing rate	Wearing rate	Age categories	Sample size	Newcastle-Ottawa Scale total score
Thompson et al.	2716781	1986-1987	1989	USA	Hospital and ED	No	7.20%	Low	All	668	8
Thompson et al.	2240332	1986-1987	1990	USA	Hospital and ED	No	19.70%	Low	All	531	8
Spaite et al	1942172	1986-1989	1991	USA	ED	No	40.90%	Medium	All	284	7
McDermott et al.	8315679	1987-1989	1993	Australia	Hospital	No	15.30%	Low	All	1710	5
Mainarus et al.	8019309	1992	1994	UK	ED/Police	No	11%	Low	All	1042	5
Thomas et al.	8312768	1991-1992	1994	Australian	Hospital	Yes	41%	Medium	Child	403	6
Thompson et al.	8971066	1992-1994	1996	USA	ED/Police	No	39.50%	Medium	All	3390	7
Li et al.	7602626	1989-1992	1995	USA/Canada	Hospital	No	1.10%	Low	Child	1538	5
Finvers et al.	8673566	1991-1993	1996	Canada	ED/Police	No	13.70%	Low	Child	699	5
Jacobson et al.	9659772	1991-1995	1998	Australia	ED/Police	Yes	28.6%-74%	Medium-High	All	229	5
Linn et al.	9666366	1991-1995	1998	Canada	ED/Police	No	22.40%	Low	Child	1462	3
Shafi et al.	9498409	1993-1995	1998	USA	Hospital	Partially	10%	Low	Child	208	3
Thompson et al.	8971067	1992-1994	1996	USA	ED/Police	No	47%	Medium	All	3388	7
Borglund et al.	10579772	1995-1998	1999	USA	Hospital	Partially	1.40%	Low	Child	125	3
Hansen et al.	14630557	2001-2002	2003	Norway	ED/Police	No	21%	Low	All	991	7
Heng et al.	16645684	2004-2005	2006	Singapore	Hospital	No	10.60%	Low	All	160	3
Airaksinen et al.	21050609	2004-2006	2010	Finland	ED/Police	No	13%	Low	All	151	4
Sze et al.	NA	2004-2006	2011	Hong Kong	Hospital	No	2.20%	Low	All	682	4
Dinh et al.	21077822	2008-2010	2010	Australia	Hospital	Yes	84%	High	Adult	287	5
Amoros et al.	21606469	1998-2008	2012	France	Hospital	No	26%	Medium	All	8373	6
Crocker et al.	21764537	2006-2009	2012	USA	Hospital	No	32.40%	Medium	Adult	420	3
Wagner et al.	23025942	2008-2010	2012	USA	Hospital	No	32%	High	Adult	163	3
Bambach et al.	23377086	2001-2009	2013	Australia	Hospital	Yes	75.40%	High	All	6745	5
Dinh et al.	23641988	2008-2009	2013	Australia	Hospital	Yes	63.60%	High	Adult	110	5
McIntosh et al.	NA	2008-2009	2013	Australia	Hospital	Yes	63.50%	High	All	137	5
Webman et al.	24158210	2008-2011	2013	USA	Hospital	Partially	30.20%	Medium	All	374	5
Lindsay & Brussoni	24991770	2004-2009	2014	Canada	ED/Police	Partially	55.30%	High	Child	15569	3
Malczyk et al.	NA	2012-2013	2014	Germany	Hospital	No	16.70%	Low	All	543	3
Otte & Wiese	NA	2000-2011	2014	Germany	ED/Police	No	10.20%	Low	All	4245	3
Zibung et al.	26038000	2010-2012	2014	Sweden	Hospital	No	43.50%	Medium	Adult	186	4
Dinh et al.	25939667	2012-2014	2015	Australia	Hospital	Yes	79%	High	Adult	254	3
Gulack et al.	26044110	2007-2011	2015	USA	Hospital	Partially	22.10%	Low	Child	7678	3
Harada et al.	26493212	2002-2011	2015	USA	Hospital	Partially	26%	Medium	All	505	3
Kaushik et al.	27747748	2002-	2015	USA	ED/Police	No	15.50%	Low	Child	567	3

		2011									
Sethi et al.	26254573	2012-2014	2015	USA	Hospital	Partially	39.10%	Medium	All	699	4
Olofsson et al.	NA	1993-2006	2017	Sweden	ED/Police	No	57.80%	Medium	Child	3711	4
Bergenstal et al.	22792660	2008-2010	2012	USA	Hospital	Yes	8.40%	Low	Child	371	4
Juhra et al.	22105099	2009-2010	2012	Germany	Hospital	No	6.40%	Low	All	2250	4
Rizzi et al.	NA	2003-2012	2013	Sweden	Hospital	No	33.10%	Medium	All	55220	4
Orsi et al.	24448470	2000-2010	2014	Germany	Hospital	No	14.90%	Low	All	242	4
Joseph et al.	27596799	2012	2017	USA	Hospital	No	25.10%	Medium	All	6267	5
Olivier et al.	NA	2001-2009	2016	Australia	ED/Police	Yes	76%	High	All	6745	5
Phillips et al.	NA	2003-2010	2016	USA	Hospital	Partially	21%	Low	Child	16681	7
Wall et al.	29564357	2008-2014	2016	USA	Hospital	No	33.30%	Medium	All	825	3
Helak et al.	NA	2002-2010	2017	USA	ED/Police	Partially	20.60%	Low	All	9174	4
Kuo et al.	27753508	1998-2013	2017	Taiwan	Hospital	No	10.60%	Low	All	812	3
Cooke et al.	NA	1984-1992	1993	Australia	Hospital	Yes	20%	Low	All	64	3
Rivara et al.	9213156	1992-1994	1997	USA	ED/Police	No	51%	High	All	3384	3
Persaud et al.	23071369	2006-2010	2012	Canada	Hospital	Partially	26.40%	Medium	All	129	3
Hooten & Murad	24661125	2005-2010	2014	USA	Hospital	Partially	18.90%	Low	All	249	3
Bandte et al.	29277588	2009-2014	2018	Germany	Hospital	No	25%	Medium	Child	55	3
Benjamin et al.	30543361	2010-2014	2018	USA	Hospital	No	36%	Medium	Adult	85187	3
McAdams et al.	29843009	2006-2015	2018	USA	ED	Partially	27.20%	Medium	Child	66897	3
Stier et al.	30878274	1999-2015	2019	Germany	Research Institute	Not metioned	11.80%	Low	All	7004	3
Harvey et al.	28751943	1999-2015	2017	USA	ED	Partially	50%	High	All	417	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 (0.45,0.88)	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.

Figures

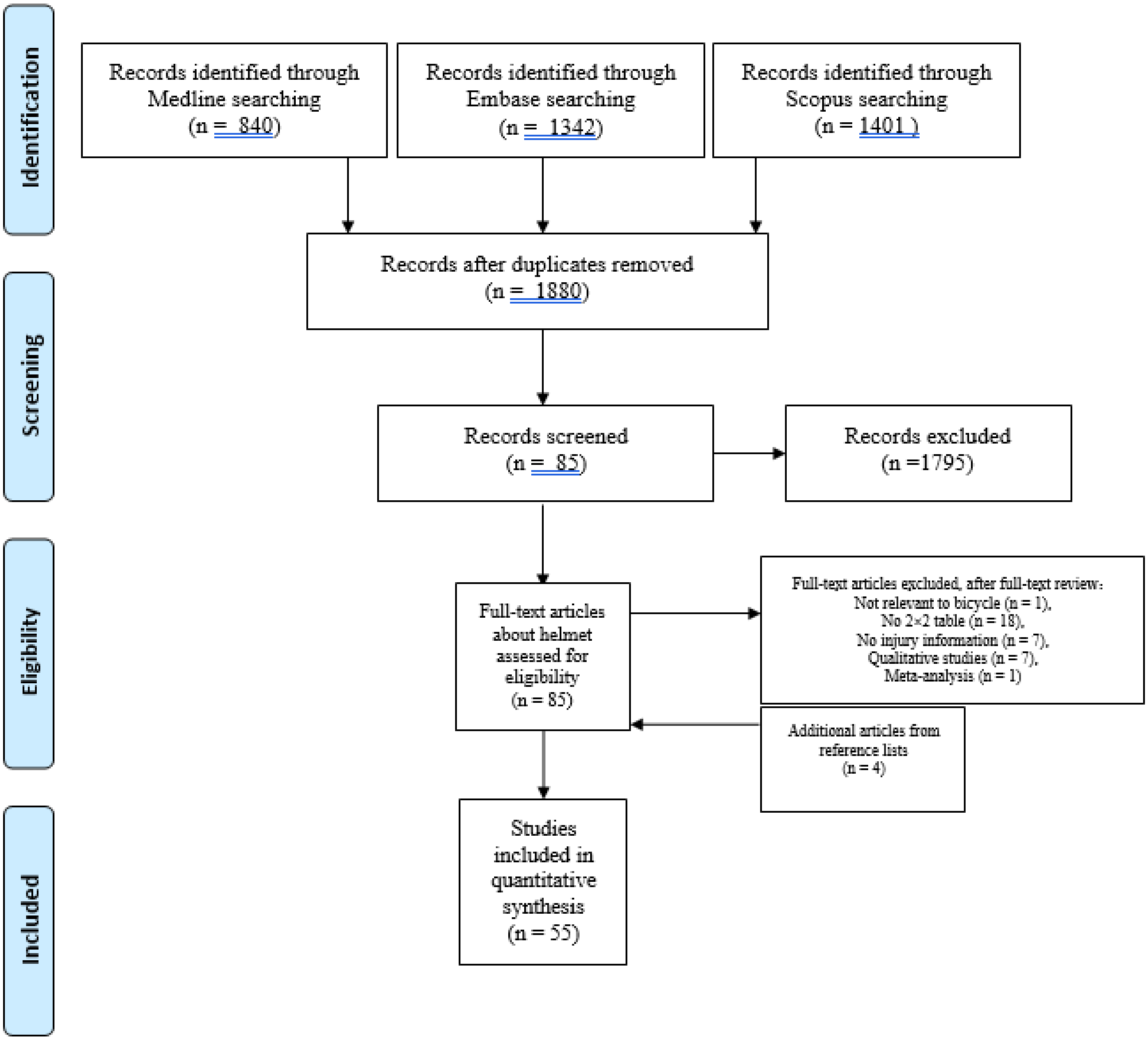

Figure 1

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.

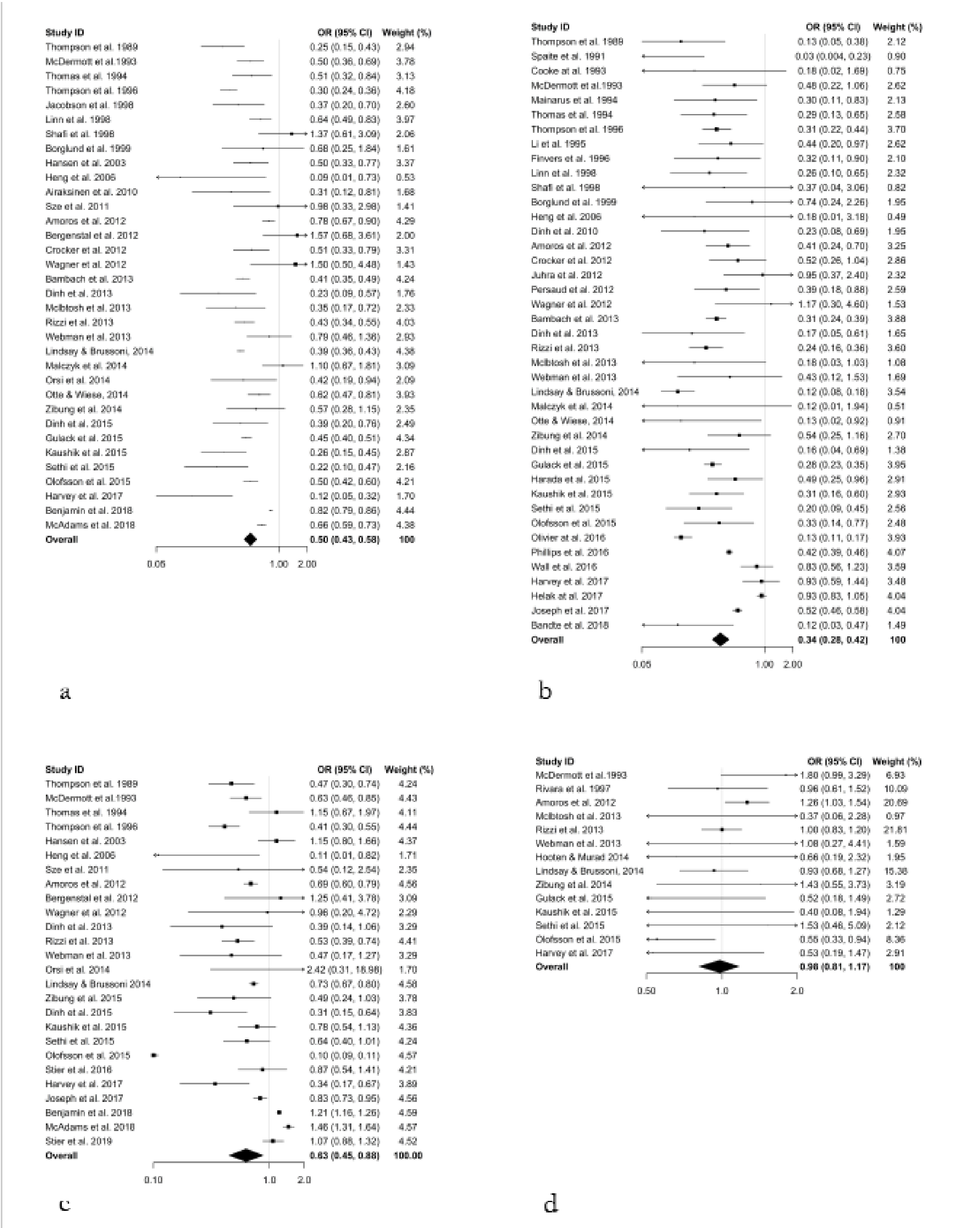

Figure 2

Forest plot of helmet effects on head injuries, serious head injuries, face injuries, and neck injuries. a.The odds ratio of helmet effect on head injuries compared with other injuries are 0·50 (95% CI: 0·43, 0·59). b. The odds ratio of helmet effect on serious head injuries compared with other injuries are 0·34 (95% CI: 0·28, 0·43). c. The odds ratio of helmet effect on face injuries compared with other injuries are 0·63 (95%

CI: 0·45, 0·88). d. The odds ratio of helmet effect on neck injuries compared with other injuries are 0·98 (95% CI· 0:81, 1·17).

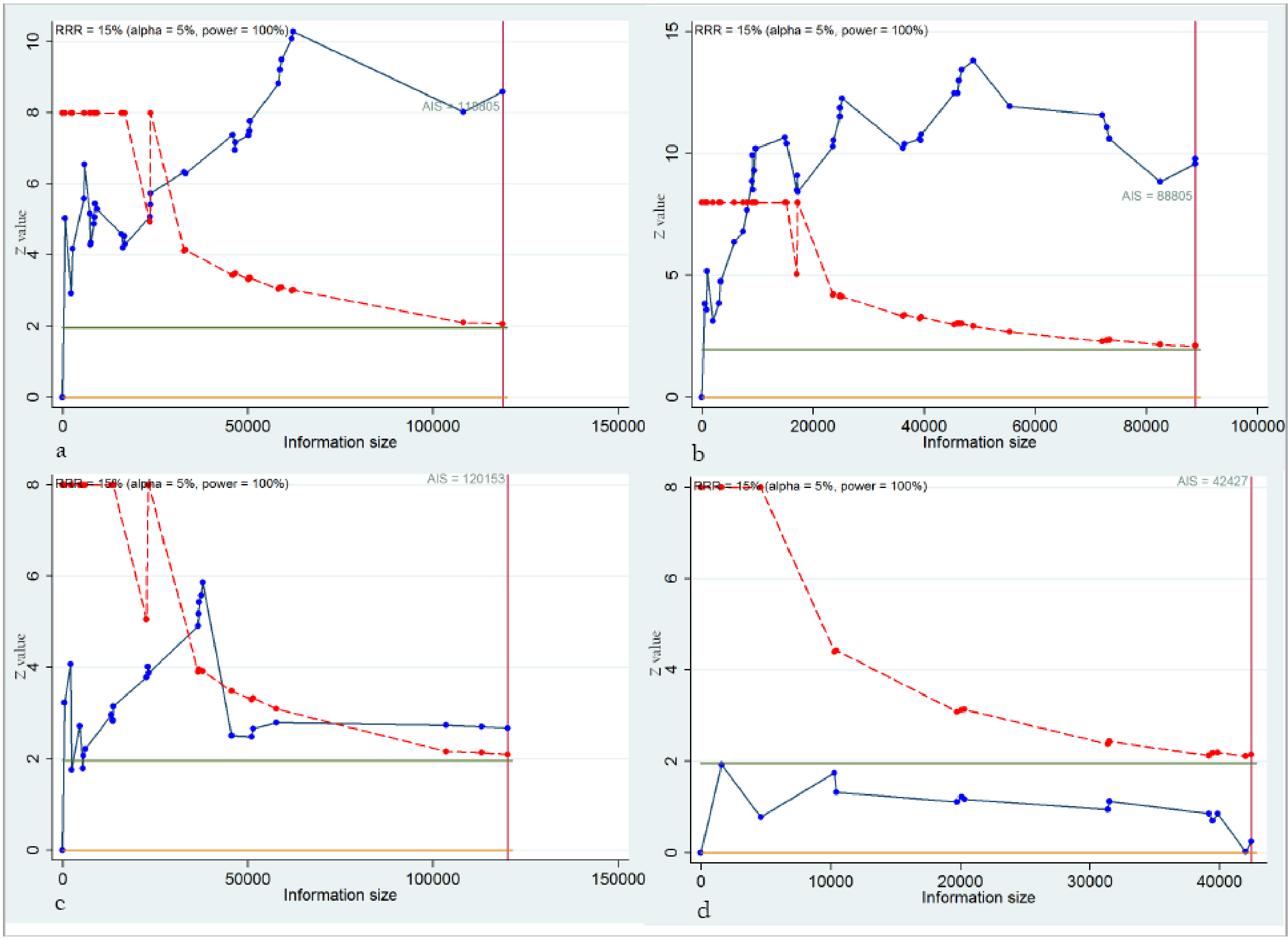

Figure 3

SSA results of helmet effects on head injuries, serious head injuries, face injuries, and neck injuries. The Y-axis label means statistical Z-value and the vertical green line means Z equals 1.96. The X-axis label is named information size as which increases it means the sample size accumulates. The red-line means study sequence analysis threshold and the blue-line means the situation of our sample. The relative position of the red-line, blue-line, and green-line will show whether the sample size could show statistical significance and is sufficient to support the results. If the blue-line passed the Z value which equals 1.96 but the blue-line did not pass the study sequence analysis threshold line, it suggests the result may be a false positive. If the blue-line passed the Z value which equals 1.96 as well as passed the study sequence analysis threshold line,it suggests the result can be very stable. If, when the sample size accumulates, the blue-line could still not pass the Z value line and study sequence analysis threshold line currently, maybe in the future it will pass the two lines with the increase of sample size. If, when the sample size accumulates to the maximum in our pooled samples, the blue-line could not pass the Z-value which equals to 1.96 in the end, it suggests the results is sufficient to show the identity of statistical nonsignificance. In a, b, and c, which represent the situation of helmet effects on head injuries, serious head injuries, and face injuries, the blue-lines all passed Z-value which equal 1.96 and study sequence analysis threshold line. In d, which represents the situation of helmet effects on neck injuries, the blue-line did not pass Z-value which equals to 1.96 and study sequence analysis threshold line.

Supplementary Files

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- SupplementaryTable1.NewcastleOttawaScalescore.docx
- SupplementaryFigure6.SSAneckinjuries.pdf
- SupplementaryFigure4.SSAseriousheadinjuries.pdf
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- PRISMA2009checklist.pdf
- SFigure3.Studysequenceanalysisofsubgroupanalysis.pdf
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