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Cycling and Walking Safety: a rapid evidence assessment for the Department for Transport

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1 Executive summary

Background

Participation in walking and cycling can bring a range of benefits to the individual, the environment and society. The benefits that come with cycling and walking are central to the UK Government's Cycling and Walking Investment Strategy. This strategy, launched in 2017, aims to significantly increase cycling activity while reducing its risk and significantly increase overall walking activity. In the UK, recent high-profile incidents involving cyclists and pedestrians led to an urgent review of cycling safety and have focussed attention on the risk and perceived risk of cycling and walking (Department for Transport 2018). Maximising participation in walking and cycling necessitates that cyclists and pedestrians feel safe. Pedestrian and cyclist perceptions of safety will, in turn, be influenced by actual levels of safety.

Objective

This rapid evidence assessment draws on systematic processes to explore whether cycling and walking interventions are effective in reducing risk and perceived risk to participants and whether this can be done without adversely affecting cycling and walking participation.

Methods

The review took the form of a rapid evidence assessment (REA) – a tool for systematically finding and synthesising available research as comprehensively as possible within the constraints of a given timetable.

Search: We undertook a systematic search of relevant databases and websites. We also contacted experts in the field to solicit potentially includable studies.

Inclusion criteria: We included studies examining cycling and walking interventions that fitted within any of five categories set out in the Department for Transport's call for evidence (DfT 2018): infrastructure and road sign interventions; interventions concerning the law and rules of the road; training and testing interventions; road user education interventions and vehicle and equipment interventions. We included studies with an experimental or quasi-experimental design, other quantitative methods that rely on correlation or association, or evidence reviews including such studies. Studies also had to examine either risk or perceived risk to pedestrians or cyclists as an outcome and needed to be of an intervention in Europe, North America or Australasia.

Results and study prioritisation: Studies were screened at title and abstract, and at full-text by a single reviewer. We used machine learning to prioritise the most relevant results from our search for screening. A total of 114 studies met our criteria for inclusion in the REA. Given the need for an efficient REA process, we limited the number of studies included for synthesis to 51. We used a set of heuristics to determine which of the studies that met our criteria should be prioritised for synthesis. The findings of the 51 prioritised studies were synthesised narratively. The findings section and review conclusions are therefore based on a proportion of all includable studies and do not comprehensively summarise all potentially relevant evidence.

The prioritisation process was intended to ensure that evidence for all intervention categories was included in the REA. However, some categories, such as the 'infrastructure and road signs category', are better evidenced than others. This is partly because the categories themselves are uneven in scope, with some covering far more intervention types than others. This is also a reflection of the pattern of available evidence, with a greater evidence base available for some intervention types. For example there is a wide evidence base on cycle helmets, covering cycle helmet usage, helmet legislation and helmet education. The review excludes evidence reporting solely on motor-vehicle collisions. As interventions targeted at motor vehicles tend to focus on motor-vehicle collisions only, this means the majority of included studies cover pedestrian and cyclist focussed interventions.

A large number of included studies are evidence reviews that cover multiple settings and intervention types. The final 51 studies included for synthesis included only a limited number of European primary studies and these were complemented by more recent primary studies from America and Australasia.

Conclusions

Overall, there is evidence backed by one or more reviews or multiple primary studies that indicate several types of intervention can reduce risk for cyclists and pedestrians. These include traffic calming measures such as road (or speed) humps, speed cameras, speed restrictions (typically evidence relates to 20 mph limits), street lighting, safe routes to school, behavioural interventions to improve safety practices, vehicle standards and safety measures, cycle helmets and visibility clothing and equipment.

There is also a set of interventions for which the evidence is more mixed. Overall, the evidence on cycle lanes and on cycle tracks that physically separate cyclists from motor traffic is inconclusive. There is no clear evidence that cycle lanes reduce risk, but physically separated cycle tracks may be more likely to reduce risk for cyclists. Cycle track design, particularly at intersections, is vital in determining effectiveness. Conversion of intersections to roundabouts with marked cycle lanes may increase cycle collisions, whereas conversion to roundabouts with cycle tracks may reduce risk of collision. There is evidence from various evidence reviews that helmet legislation can reduce head injuries, but more recent reviews and primary studies indicate mixed findings.

To be included in our review, studies had to report a measure of risk or perceived risk to cyclists or pedestrians. Few studies that met this inclusion criterion also report on the effect of programmes on cycling or walking participation. As a result, it is difficult to assess whether any observed reduced risk could be offset by (or the result of) reduced participation. However, regarding cycling helmet legislation, one literature review indicates that, if there is any effect, it is one of a short-term reduction in child cycling participation. A second literature review reports that helmet legislation in New Zealand reduced cycling participation.

Many of the cycling and walking interventions covered in this REA show promise for reducing risk or perceived risk for cyclists and pedestrians. However, there is a lack of well-designed evaluations that adequately control for bias and also a lack of evidence that explores impact on both risk and participation.

2 Introduction

2.1 The problem

The benefits that come with cycling and walking are central to the UK Government's Cycling and Walking Investment Strategy. The Strategy, launched in 2017, aims to (a) significantly increase cycling activity while reducing its risk and (b) significantly increase overall walking activity, with a special focus on increasing the percentage of children aged five to ten that usually walk to school from 49% in 2014 to 55% in 2025.

The focus on increasing participation in walking and cycling is informed by the range of benefits these activities bring to the individual, the environment and society (Celis-Morales et al. 2017; Department for Transport 2018; Mulvaney et al. 2015; Reynolds et al. 2009; Pucher and Buehler 2008; Teschke et al. 2012). Both activities help to prevent and manage health conditions (e.g. cardiovascular disease, type 2 diabetes) as well as positively impacting individuals' mental health. Cycling and walking can also produce economic benefits when compared to sedentary transport[1] by promoting increased productivity and reduced absenteeism at work (Department for Transport 2017). Cycling and walking require few financial resources on the part of the user (in the case of cycling) or none (in the case of walking) and are therefore affordable and equitable ways of getting around (Pucher and Buehler 2008). They also reduce noise, air pollution and emission of greenhouse gases (Reynolds et al. 2009) – key considerations in light of the UK Government's aim to reduce greenhouse gas emissions (Department for Transport 2018).

The Cycling and Walking Investment Strategy aims to integrate cycling and walking into people's everyday lives while recognising that increasing participation is contingent on decreasing the risk or perceived risk associated with both activities, notably cycling. In this context, risk and perceived risk[2] relate to the risk or perceived risk of a collision[3], although it is important to note that one (i.e. reducing risk) can exist without the other (i.e. reducing perceived risk). Equally, reducing perceived risk is not automatically accompanied by reducing risk.

Safety concerns are a significant barrier to cycling (Asgarzadeh et al. 2017; Department for Transport 2016; London Assembly and Transport Committee 2012; Teschke et al. 2012) and can be heightened by road infrastructure which is not fit for purpose for cycle traffic. Roundabouts, for example, have been cited as a major deterrent to cycling (Reynolds et al. 2009; Yor et al. 2015). Other deterrents to cycling cited in the literature include cyclists' perceptions that motorists do not know how to drive safely when closely interacting with cyclists; the general risk of collisions with cars; or the risk of cycling on heavily congested roads (Reynolds et al. 2009). These perceptions are more common among demographic groups such as the elderly, children and women (Pucher and

[1] Sedentary transport describes transport that involves sedentary behaviour (e.g. travelling by train or bus), i.e. transport that does not involve physical activity
[2] We use the term 'risk' throughout the review process to refer to risk or danger to cyclists and pedestrians.
[3] We use the term 'collision' throughout in place of 'crash' or similar terms.

Buehler 2008). For instance, in 2016, 59% of British people agreed with the statement "It is too dangerous for me to cycle on the roads", with older people, females and non-cyclists the most likely groups to agree with this statement (Department for Transport 2018).

However, research indicates that increased participation in cycling reduces the risk of cycling, a phenomenon known as the safety-in-numbers effect (Aldred et al. 2018; Madsen and Lahrmann 2017; Pucher and Buehler 2008). The example of Copenhagen illustrates this effect well: as cycling increased by 50 per cent between 1995 and 2010, the risk of cycle casualties reduced fourfold during the same period (London Assembly and Transport Committee 2012). Cycling injury and fatality rates per distance travelled thus tend to be higher in countries such as the UK where cycling is less common than in Northern European countries such as Denmark (Pucher and Buehler 2008; Teschke et al. 2012). When examining cycling rates in the UK, however, it is also important to be mindful of regional differences in cycling rates; cycling rates in London are higher than in other parts of the UK, driven in part by the relative investment into cycling infrastructure (Department for Transport 2018).

Perceptions of risk also impact walking rates. For instance, pedestrians are more likely to avoid walking in areas with a higher risk of pedestrian collisions such as those with high levels of speeding motor vehicles (Quistberg et al. 2015). In the UK, parents often feel the need to accompany their children when they walk to school, while road safety and access can be a concern for disabled or older pedestrians (DfT 2014, Lee, 2016, TfL 2016). Changes to the law and rules of the road, such as introducing speed limits, potentially reduce the risk of collisions while encouraging more people to walk as well as cycle (European Transport Safety Council 2015).

In the UK, recent high-profile incidents involving cyclists and pedestrians led to an urgent review of cycling safety and have focussed attention on the risk and perceived risk of cycling and walking (Department for Transport 2018). While motorists pose by far the biggest risk to cycling and walking, cyclists can also endanger pedestrians: in 2016, three pedestrians died and a further 108 were injured in collisions with cyclists – a figure that has doubled since 2006 (Scott 2017). Such figures, however, should be treated with caution, as they do not establish who was at fault.

Maximising participation in walking and cycling, as envisaged by the Strategy, therefore necessitates that cyclists and pedestrians feel safe. Pedestrian and cyclist perceptions of safety will, in turn, be influenced by actual levels of safety.

2.2 Description of the interventions

The interventions of interest are geared towards reducing the risk, and perceived risk, of cycling and walking in those public places where cycling and walking may interact with motor vehicles. The intended benefits of such interventions include decreasing the risk of collisions and fatalities as well as enhancing participation rates that come with an increase in safety or perceived safety. This review examines different types of intervention to reduce the risk, and perceived risk, of cycling and walking. These five intervention types are based on the recent Department for Transport call for evidence (DfT 2018) and include: (a) infrastructure and road sign interventions; (b) interventions concerning the law and rules of the road; (c) training interventions; (d) road user education interventions; and (e) vehicle and equipment interventions. We define these interventions in greater detail in the interventions section of our criteria for including and excluding studies, in section 4.

2.3 How the interventions might work

This rapid evidence assessment is designed to include evidence on a wide range of interventions, each of which aims to address risk in different ways. Some interventions aim to eliminate some forms of risk, for example, through infrastructural changes such as cycle tracks that physically separate cyclists from motor traffic on carriageways. Some interventions attempt to mitigate risk by changing behaviour, for example by providing warning signs or advance stop signs (a type of second stop line in advance of the normal stop line at signalised junctions) or educating pedestrians, cyclists or motorists. Others such as providing cyclists with protective equipment such as cycle helmets aim to deal with any latent risk and reduce the gravity of injuries, should they occur. Thus, the set of interventions covered by this review can be conceptualised as fitting within a hierarchy in which interventions designed to eliminate risk are at the top and those that attempt to mitigate or deal with latent risk are at the bottom, similar to those used for prevention and control measures for occupational health and safety (HSE 2018; OSHWiki 2018).

2.4 Why it is important to do the rapid evidence assessment

There exists a real governmental appetite to increase walking and cycling due to the benefits of these activities. A recent DFT review on cycling and walking highlights the practical relevance of a review exploring the effectiveness of walking and cycling interventions in promoting safety: “It would clearly be extremely helpful to demonstrate to prospective cyclists that previously reticent cyclists had either overcome their safety fears (…) or had discovered that new infrastructure (or some other intervention) had helped them address their safety concerns” (Department for Transport 2016). This rapid evidence assessment (REA) aims to draw on systematic processes to locate a body of evidence that can explore whether cycling and walking interventions are effective in reducing risk and perceived risk to participants and whether this can be done without adversely affecting rates of participation.

3 Study objectives

The overarching question for the rapid evidence assessment is as follows:

What evidence is there regarding the effectiveness of interventions to reduce the risk, and perceived risk, of cycling and walking? Furthermore, what evidence is there of the effect of such interventions on participation in walking and cycling?

This overarching question is further broken down into the following 5 research questions, based on the recent Department for Transport call for evidence (DfT 2018):

1. How effective are different **infrastructure and road sign** interventions at reducing the risk, and perceived risk, of cycling and walking?

2. How effective are different interventions concerning the **law and rules of the road** at reducing the risk, and perceived risk, of cycling and walking?

3. How effective are different **training interventions** at reducing the risk, and perceived risk, of cycling and walking?

4. How effective are different **road user education interventions** at reducing the risk, and perceived risk, of cycling and walking?

5. How effective are different **vehicle and equipment** interventions at reducing the risk, and perceived risk, of cycling and walking?

4 Methodology

4.1 Overview

This review takes the form of a Rapid Evidence Assessment (REA)[4]. Our criteria and processes for determining study inclusion of evidence, extracting data and synthesising findings are summarised below. See Appendix 1 for a comprehensive description of our inclusion criteria.

4.2 Inclusion criteria

To be included, studies had to explore one of the following five broad categories of interventions. See Appendix 1 for a full list of all types of includable interventions:

a. *Infrastructure and road sign interventions* such as traffic lights, junctions and crossings, cycle facilities and footways, or traffic signs.

b. *Interventions concerning the law and rules of the road* including implementation and enforcement of road traffic legislation and rules like the Highway Code, and including interventions such as mandatory helmet wearing, stricter/presumed liability, insurance and speed limits.

c. *Training and testing interventions* such as those around obtaining and maintaining driving qualifications and training for cyclists and others in cycle safety or for pedestrians in safe road crossing.

d. *Road user education interventions* such as school based, media or rehabilitation education programmes.

e. *Vehicle and equipment interventions* such as standards, maintenance programmes and safety features for vehicles, and safety features and equipment for bicycles and cyclists.

The aim of this REA is to provide evidence on the effectiveness or otherwise of cycling and walking interventions in reducing risk or perceived risk, and to further explore any effect on participation. The most relevant study designs in addressing this question were judged to be those that provide a quantitative measure of the net change in outcomes attributable to an intervention or policy. As a result, we included studies with an experimental or quasi-experimental study design, other quantitative methods that rely on correlation or association, or evidence reviews including such studies.

To be included, studies also had to examine either risk or perceived risk to pedestrians or cyclists as an outcome. Examples of outcome constructs for risk include absolute or

[4] "A Rapid Evidence Assessment (REA) is a tool for getting on top of the available research evidence on a policy issue, as comprehensively as possible, within the constraints of a given timetable." Davies et al. 2003. Rapid Evidence Assessment Toolkit

relative numbers of collisions, fatalities, injuries, near misses, or the severity of collision or injury. Examples of outcome constructs for perceived risk include the perceived risk of collision, injury or fatality.

Studies also needed to be of an intervention in Europe, North America or Australasia. We included studies in English from either the published or unpublished (grey) literature. Primary studies were only includable if published in 2005 or after. Evidence reviews were includable if published in 2000 or after.

4.3 Search strategy

We undertook a systematic search of relevant databases and websites/online repositories. We contacted the Universities' Transport Study Group (UTSG), the University of Leeds Institute for Transport and Cycling and Society Research Group (CSRG) and other experts in the field to solicit potentially includable studies. We also screened a limited number of hits in Google and Google Scholar using bespoke versions of our search string employing a combination of terms such as ((walk* OR pedestrian*) OR (cycle* OR bike*)) AND evaluation.

A list of databases and websites/online repositories that were searched is provided in Appendices 2 & 3. We also set out an example of our full search string for database searches in Appendix 4.

4.4 Screening and study prioritisation

Studies were screened at title and abstract, and at full-text. Before each stage, screening tools were piloted by a group of reviewers to promote inter-screener reliability. We used Rayyan systematic review software at title and abstract stage (see Ouzzani et al. 2016). The software uses machine-learning algorithms to learn from inclusion and exclusion decisions and allowed us to prioritise more relevant results for screening.

Given the short time period available to the research team to complete this REA, the number of studies included for synthesis was limited to approximately 50 (actual number included for synthesis = 51). We used a set of heuristics based on intervention type, outcome, setting, study design and publication date to determine which of the studies that met our criteria for inclusion at full-text should be prioritised for synthesis. See Appendix 1 for more details.

4.5 Data extraction and synthesis

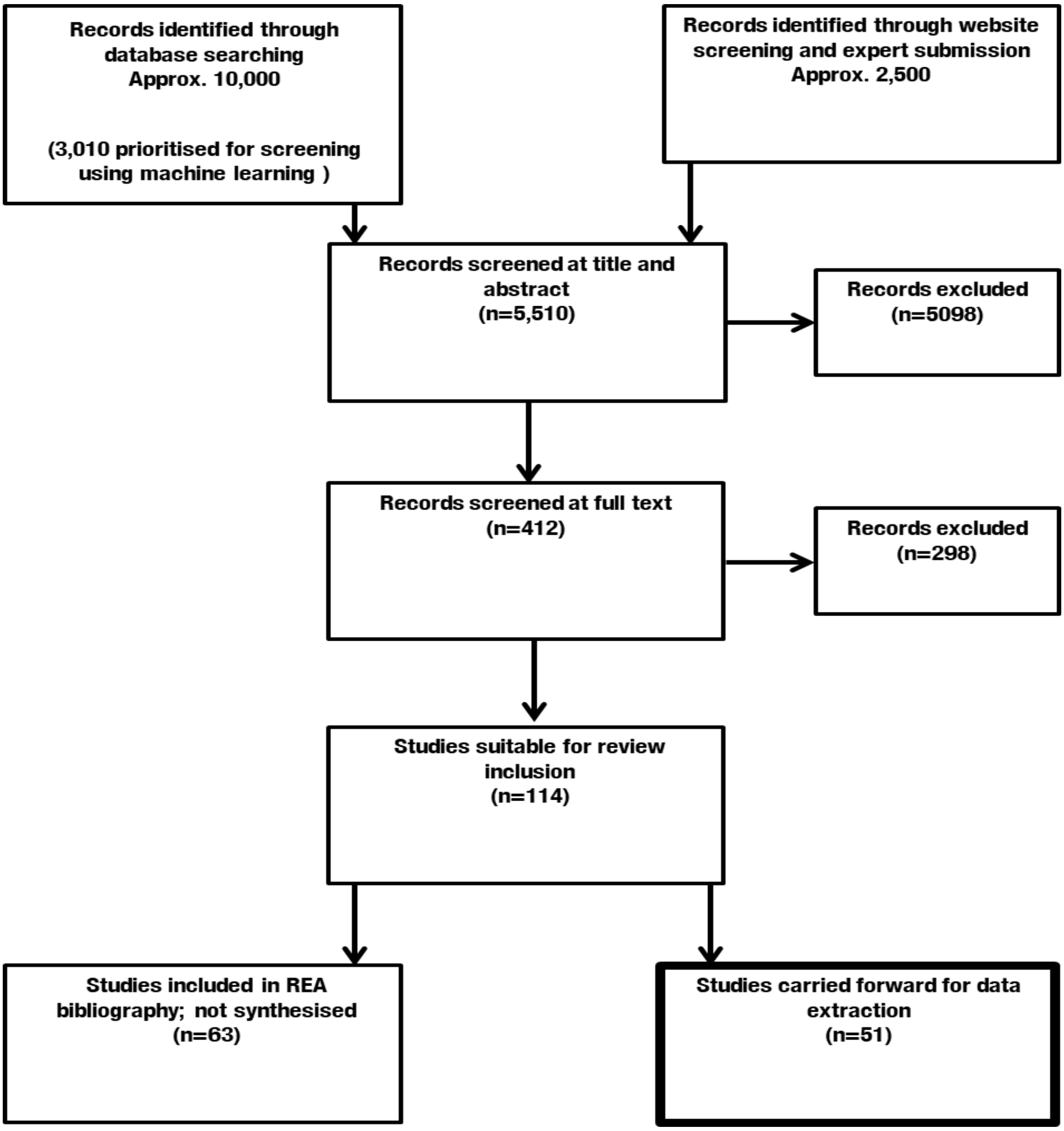
Data extraction tools were piloted before use, after which data extraction was undertaken by a single researcher with key aspects double-coded by a senior researcher. Appendix 5 provides an overview of our data extraction template.

Following data extraction, we narratively synthesised the 51 prioritised studies. Evidence is reported separately by intervention category and type and summarised in tables of characteristics presented in appendix 7. See Appendix 1 for more details on data extraction and synthesis.

5 Results

The PRISMA flowchart (Figure 1.1) summarises the REA's screening and inclusion processes.

Figure 1.1 – PRISMA flowchart: REA screening and inclusion process



There were approximately 10,000 unique results returned from systematic searches across the chosen academic databases. A total of 3,010 results were prioritised for screening at title and abstract using machine learning, of which 306 met the inclusion criteria for full text screening. 80 of these articles met the criteria for inclusion in the review. Approximately 2,500 results were screened from website review and expert submission. 106 full texts were screened at full-text, of which 34 met the criteria for inclusion in the review.

114 documents screened at full text met the criteria for inclusion in the REA. Due to the need for an efficient REA process, and reflecting the protocol, two reviewers manually prioritised 51 of the total of 114 documents meeting the criteria for inclusion, to determine which would be carried forward for data extraction and synthesis. Appendix 8 lists the remaining documents that met our inclusion criteria but were not synthesised and Appendix 6 lists evidence included for synthesis.

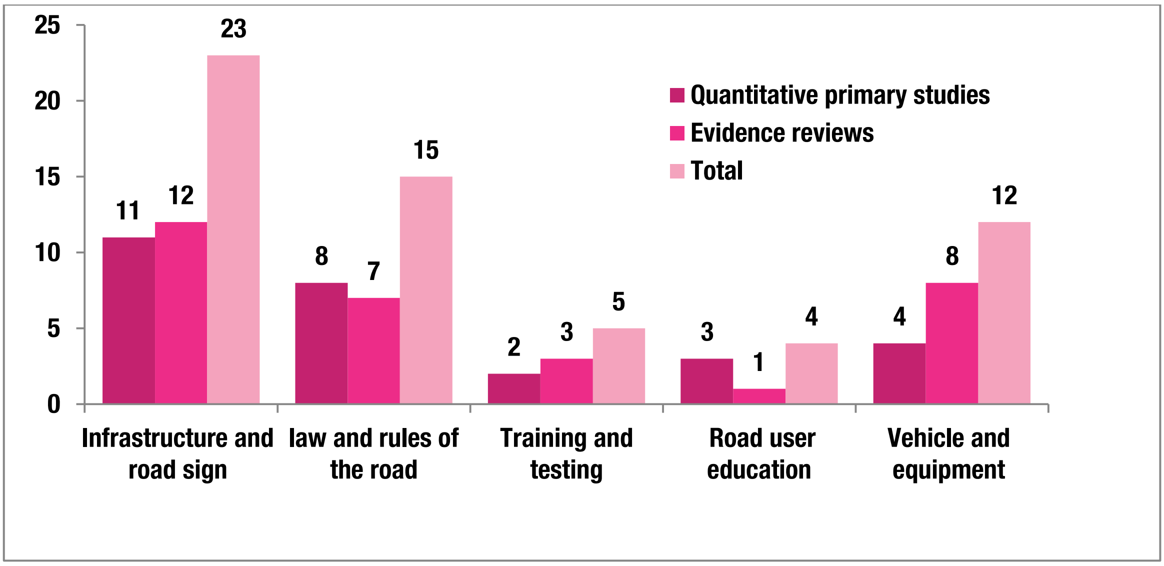
Tables of characteristics summarising the interventions, methodologies and outcomes from studies included for synthesis are provided in Appendix 7.

Description of the included studies

Due to the rapid nature of this review, we prioritised 51 of 114 includable studies for synthesis. The analysis of the results presented below and the subsequent findings apply only to the 51 studies included for synthesis.

Figure 1.2 indicates that the majority of studies included for synthesis evaluated infrastructure and road sign interventions (n=23), though it is important to note that this category is the broadest in terms of the number of different intervention types it includes. There were also substantive bodies of evidence for studies evaluating interventions covering law and rules of the road (n=15) and vehicle and equipment interventions (n=12). Fewer studies evaluated training and testing interventions (n=5) and road user education (n= 4).[5]

Figure 1.2: studies included for synthesis by intervention category



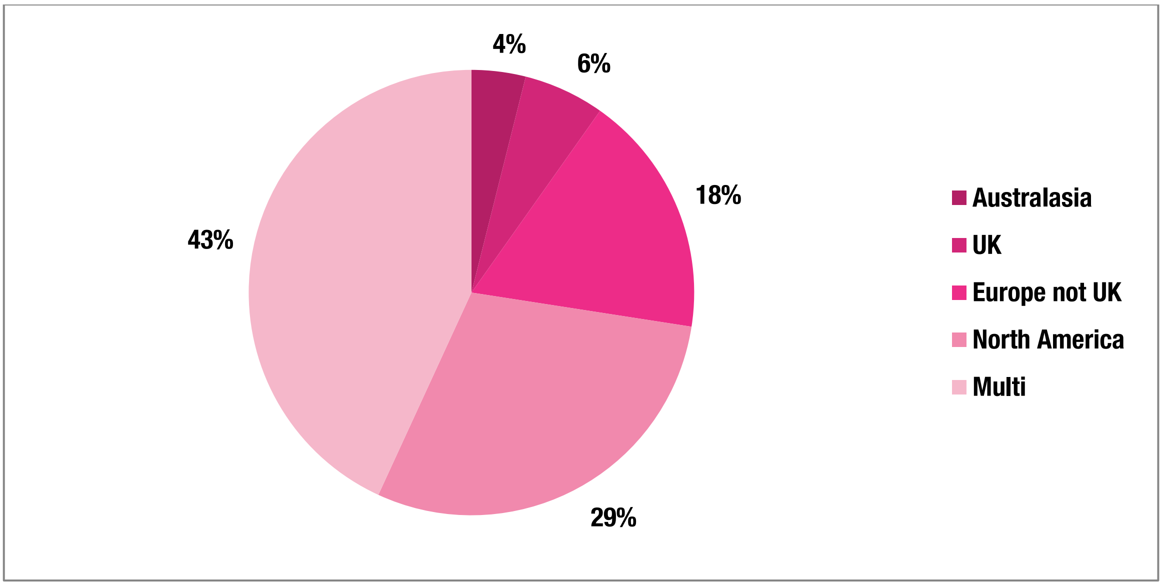
Total number of studies sums to over 51 as various studies, typically evidence reviews cover more than one intervention category.

[5] Note that total number of studies for Figure 1.2 sums to over 51 as various studies, typically evidence reviews cover more than one intervention category.

In the 51 studies prioritised for synthesis we included 24 evidence reviews and 27 quantitative primary studies. Of the evidence reviews nine described themselves as systematic reviews, one as an REA and 14 as literature reviews. Of the quantitative primary studies, four are randomised controlled trials (RCTs), three employed difference-in-differences, two are controlled before-after studies and seven are interrupted time series. Others include single group pre-test post-test (n=6), cross-sectional comparison studies[6] (n=2) and a range of others including regression models (n=2), and multilevel models (n=1).

Typically the evidence reviews include evidence from multiple country settings (though two focussed on evidence from a single country). We also identified a limited number of European primary studies (n=12), of which three evaluated interventions in the UK. These were complemented by relevant primary studies from North America (n=14) and Australasia (n=1) identified through our search.

Figure 1.3: studies included for synthesis by setting



Regarding outcomes reported by synthesised studies, only five included studies explore both risk or perceived risk and participation. Thus, the evidence base is not well-suited to exploring whether participation in cycling and walking is affected by interventions designed to reduce risk or perceived risk.

[6] In which two or more groups are compared at a single time point.

6 Findings

In the following section, we describe the findings from our 51 prioritised studies narratively. The findings section is structured by intervention category, with each of our five categories (Infrastructure and road sign interventions; Interventions concerning the law and rules of the road; Training and testing interventions; Road user education interventions; Vehicle and equipment interventions) discussed in turn. Within each of these sections, we group evidence by particular types of intervention or programme, summarising findings narratively. Descriptive tables containing a summary of study design, context, methodology and findings are provided in Appendix 7.

Note that some connected topics may appear in multiple sections; for example, helmets (evidence related to their use or not) are discussed in the section on 'vehicles and equipment', but also in law and rules of the road (cycle helmet legislation) and 'Road user education' (cycle helmet education).

In each section, findings from larger, more recent or higher quality evidence reviews including multiple studies are discussed first, before those from smaller or less rigorous evidence reviews and primary studies. We provide an indication of evidence review quality in the descriptive tables in Appendix 7. Evidence reviews are labelled as they describe themselves – as systematic reviews, REAs or literature reviews. Typically (though not always) systematic reviews can be thought of as the most rigorous and literature reviews as the least rigorous of these evidence review methodologies. However, we also report whether evidence reviews undertook a systematic search or quality appraised included studies as an indication of review quality (see descriptive tables in Appendix 7).

For quantitative primary studies, we report study design as an indication of study quality. RCTs and quasi-experimental designs such as difference-in-differences, controlled before-after or interrupted-time-series can be regarded as being more rigorous than other designs such as single group pre-test post-test and cross-sectional comparison studies. Short descriptions of these study designs are provided in Appendix 1. For explanations of other technical language, readers may wish to refer to the OECD glossary of statistical terms (OECD n.d.).

6.1 Infrastructure and road signs interventions

Infrastructure and road sign interventions

Infrastructure and road sign interventions include: management of infrastructure and signing; traffic calming measures such as road (or speed) humps; measures to reduce the impact of motor traffic (e.g. quiet lanes; road layout and design); building and maintenance of pavements/footways and cycle track/lanes; road building and maintenance; signal control (e.g. advanced stop lines, early release signals); the design, maintenance and good practice in implementation of road signs (e.g. direction signing); design of roundabouts and crossings (e.g. refuge islands).

23 studies evaluating infrastructure and road sign interventions are included in the REA for synthesis. Five of the included studies evaluate interventions on traffic calming measures and infrastructure to control speed. A further eight examine cycle tracks and lanes and other cycle infrastructure and another three investigate the design of roundabouts and junctions. Six studies address interventions on signal control, one study examines street lighting, two evaluate speed cameras and a further four studies evaluate interventions on safe routes to school[7].

Of the 23 studies, we found 12 evidence reviews (nine literature reviews, two systematic reviews of which one was combined with a meta-analysis, and one REA), five single group pre-test post-test studies, three studies with a difference-in-differences (DID) design, and two single group pre-test post-test studies. Also included is a cross-sectional comparison study.

The following section reports on these studies, grouping them by intervention type wherever relevant and beginning with evidence reviewing prior research. Table 7.1 to 7.5 in Appendix 7 summarise study settings, methodologies and outcomes.

Traffic calming and infrastructure to control speed

Reid and Adams (2011) undertake a literature review and find that traffic calming measures such as chicanes[8], pedestrian refuge islands and systematic approaches (e.g. placemaking[9]) can reduce speeds, reduce casualties for all road users and increase rates of cycling. They note that such infrastructure may disadvantage cyclists if not carefully designed with examples of increased levels of motor vehicle drivers overtaking on the approach to traffic calming measures or cyclists taking evasive behaviour to avoid traffic calming entirely.

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[7] Note that totals do not sum to 23 as some studies, typically evidence reviews, cover multiple intervention types.
[8] Chicanes require one direction of traffic to give way to oncoming vehicles.
[9] Placemaking refers to a ‘design technique that integrates urban design within the highway environment, and within traffic free routes away from the highway, to create a place with a strong identity or a memorable route, engaging successfully with its surrounding buildings and activities’ (Sustrans, 2014).

Arbogast et al. (2018) conduct a single group pre-test post-test study in the US to measure the effectiveness of installing a speed hump in reducing motor vehicle accidents involving pedestrians under the age of 21 (children and adolescents). They find a 37.5% reduction in pedestrian-involved vehicle collisions following the installation of the speed hump, though do not report statistical significance and report that they are unable to measure and control for confounding variables. The authors note that evidence indicates that speed hump height and the distance between the speed hump and pedestrian crossing can substantially reduce vehicle speeds.

Rothman et al. (2015a) report on a single group pre-test post-test study in Canada, looking at the incidence rate of pedestrian-motor vehicle collisions for roads where speed humps were installed. The researchers find that the installation of speed humps is associated with a 22 % reduction in pedestrian motor vehicle collision incidence rates involving no/minor injuries (Incidence Rate Ratio (IRR= 0.78, 95% Confidence Intervals [CIs] 0.63, 0.96), and a 20% reduction in minimal injuries requiring a visit to the emergency department (IRR = 0.80, 95% CI: 0.66, 0.96). The reduction is greater for children than for adults. The researchers conclude that speed humps provide an effective traffic calming measure, especially for children.

De Pauw et al. (2014a) undertake a pre-test post-test study examining the installation of 53 fixed speed cameras at intersections in Belgium. They find decreases in the number of injured cyclists (Odds ratio [OR] = 0.88) and pedestrians (OR = 0.63) per year per location, though statistical significance is not reported.

De Pauw et al. (2014b) apply the same pre-test post-test approach to explore the effect of installing combined speed and red light cameras[10] at 253 signalised intersections in Belgium. They find a decrease in the number of injured cyclists (Relative change = 0.78) per year, but no effect on pedestrians (Relative change = 1.04). Again, statistical significance is not reported.

Cycle tracks, cycle lanes and other cycle infrastructure

For the purposes of this review, it is important to distinguish between cycle lanes and tracks. Definitions and usages can vary (TFL 2014). Throughout, we define cycle tracks as being physically separated from a carriageway by a space, kerb or barrier, whereas cycle lanes are defined as being within a carriageway and marked by a lane dividing line[11]. Note that many evidence reviews discuss cycle tracks and lanes jointly so it is not always possible to report on these two types of infrastructure separately.

In a meta-analysis, Mulvaney et al. (2016) systematically review evidence on the effect of cycle infrastructure (such as cycle lanes, advanced stop lines, use of colour, cycle tracks, management of the road network, speed management, cycle routes and networks, roundabout design and packages of measures). In a meta-analysis of three studies, the authors find no difference in cycle collisions between a treatment group using cycle lanes

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[10] Red light cameras light cameras compare information on vehicle speed at stop lines with the signal phase in order to analyse red light running.

[11] N.B. we endeavour to apply these definitions throughout the chapter. Where studies do not explicitly define types of cycle track, lane, or others, we use ‘cycle tracks and cycle lanes’ as a catch-all phrase.

and a control group not using cycle lanes (RR = 1.21, 95% CI: 0.70, 2.08). Similarly, in a further meta-analysis of three studies and after adjusting for cycle flow, the authors find no statistically significant difference in collision rates between cyclists using ‘cycle routes and networks’ containing multiple types of cycle infrastructure and those not using them (RR = 0.40, 95% CI: 0.15, 1.05). The researchers highlight the overall lack of high quality research and emphasise how it makes it difficult to draw any firm conclusions from the meta-analysis findings.

DiGioia et al. (2017) review literature on interventions designed to increase cyclists' safety in the USA. Intervention types include the provision of cycle lanes, cycle tracks and street lighting. Given the absence of data required for a full meta-analysis, the authors report results from 19 included studies narratively. The findings for all outcomes (conflict rate, collision rate, collision severity and injury collision rate) are inconclusive.

Thomas and DeRobertis (2013) undertake a literature review of 23 studies exploring the effect of cycle tracks that separate cyclists from the motorised vehicle traffic by a physical barrier. They conclude that where cycle intersections are well designed, constructing cycle tracks reduces collisions and injuries. Key design features for effective cycle intersections are described as: bringing cycle tracks closer to the parallel vehicle traffic at intersection approach to increase cyclist visibility; Raising vehicle crossings (like a speed bump) at cycle track intersections; Using advance stop lines for motor vehicles (at least 20m before the intersection); dedicated cyclist signals to separate cyclists from turning vehicles. They also conclude that one-way cycle tracks are safer at intersections than two-way tracks (due to a lower frequency of cyclist collisions).

A rapid evidence assessment of 55 studies considered a wide range of interventions including some related to physical infrastructure such as bike lanes, walkways and signage (Brook Lyndhurst 2016). The review reports on study findings narratively, finding that segregated cycle tracks lead to a lower risk of cyclist injury as well as accidents. They also indicate that coloured bicycle lanes and bicycle phases in traffic signals also can be effective in reducing collisions.

Reynolds et al. (2009) undertake a literature review of 23 studies on the impact of transportation infrastructure on cyclist safety at intersections (e.g. roundabouts, traffic lights) or between intersections on ‘straightways’ (e.g. bike lanes or tracks). Reynolds et al. note that evidence is sparse; they nonetheless identify some key findings from the evidence. Purpose-built bicycle only facilities (e.g. cycle tracks and lanes) reduce the risk of collisions and injuries compared to cycling on-road with traffic or off-road with pedestrians. They do not explore results separately for cycle tracks and lanes. However, the authors also find that street lighting, paved surfaces, and low-angled grades also appear to improve cyclist safety.

Reid and Adams (2010) undertake a literature review and find little evidence that marked cycle lanes provide benefit on measures of risk for cyclists. However, segregated networks may reduce risk or severity of collisions for cyclists but the authors note that sections where they intersect with roads may offer heightened risk and offset the overall benefit. They conclude segregated networks may be more appropriate in rural settings where there are fewer intersections. They also find evidence that some continental

European networks perform better than UK networks and this may be because they include physical measures to slow vehicle traffic at points where they intersect with segregated cycle tracks.

Usami and Amarri (2017) review literature on the effectiveness of visually protected cycle lanes and physically protected cycle tracks on the number of bicycle accidents. Drawing largely on meta-analysis results from a single study, the authors conclude that the installation of cycle lanes leads to a small though non-statistically significant reduction in bicycle accidents. Furthermore, they find that physically separated cycle tracks may result in an increase in bicycle accidents (no further outcome definition provided), particularly at intersections.

Reid and Adams' 2010 literature review also concludes that Cycle Advanced Stop Lines are frequently not respected by road users and furthermore that they show little benefit on measures of risk for cyclists. Brook Lyndhurst's 2016 Rapid Evidence Assessment supports this, finding that while advance stop lines do not seem to increase cyclist safety, they increase cyclists' perception of safety.

Design of roundabouts and junctions

Soteropoulos and Stadtlbauer (2017) undertake a literature review of 18 studies from a range of countries to study the safety effects for cyclists resulting from the conversion of junctions to roundabouts. The evidence is mixed with some studies reporting statistically significant positive effects on decreasing bicycle collisions, while others reporting statistically significant negative effects or no statistically significant change. The authors conclude that the safety effects of junction conversions to roundabouts depend largely on the precise geometry and type of cycle infrastructure implemented, with worse findings for cycle lanes, but reductions in accident frequency for roundabouts with cycle tracks. Mulvaney et al. (2016) echo this conclusion from a narrative review of evidence, concluding that conversion of intersections to roundabouts with marked cycle lanes increases cycle collisions, whereas conversion of intersections with and without signals to roundabouts with physically separated cycle tracks may reduce risk of collision.

Reid and Adams' 2010 literature review finds that raised cycle track crossings, cycle lanes that continued across junctions and signalisation of large roundabouts can all reduce rates of cyclist casualties.

Retting et al. (2003) undertake a literature review and find that single-lane roundabouts, pavements and pedestrian refuge islands reduce the risk of pedestrian-motor vehicle collision.

Signal control

Kennedy and Sexton (2009) conduct a literature review of road safety at traffic signals and signalised crossings. The authors note the limited evidence base, but tentatively conclude that signalised crossings reduce pedestrian collisions. They find limited evidence that signal-controlled roundabouts are safer than normal roundabouts, especially for cyclists and that puffin and pelican[12] crossings have a similar safety record (in terms of frequency of pedestrian collisions). Based on a non-UK evidence base, they also find that signals allowing right turn on red lights (or left turn on red if it were in the UK) increase pedestrian and cycle collisions with vehicles.

Fitzpatrick et al. (2011) summarise evidence from the United States regarding various engineering countermeasures aimed at improving pedestrian and cyclist safety in the United States including: the High intensity Activated crossWalK (HAWK)[13] and shared lane markings or sharrows[14]. The single study indicates that HAWK led to a decrease in both total collisions (any type of collision) and pedestrian collisions. Findings from a further single study for shared lane markings or sharrows were inconclusive.

Retting et al. (2003) undertake a literature review and find that the following show promise (there is only a limited evidence base) for their impact on pedestrian motor vehicle collision risk: advance stop lines, in pavement flashing lights, automatic pedestrian detection at walk signals and exclusive pedestrian signal phasing which stops all vehicle traffic for part or all of the pedestrian crossing signal (note that in the United States, vehicles may be permitted to turn at a junction even when the pedestrian signal is green, whereas this is not the case in the United Kingdom).

Given the limited available evidence base from reviews, we also summarise findings from several primary studies that met our inclusion criteria and scored high on relevance (see section on Methodology). Using a single group pre-test post-test design, Porter et al. (2016) investigate the effects of rectangular rapid flash beacons on US college students' perceptions of safety. The researchers use a 5-item Likert scale to assess how safe students feel when crossing streets around campus (with 1 meaning extremely unsafe and 5 extremely safe), finding a statistically significant positive effect on perceived risk. However, they find no statistically significant change for self-reported occurrences of near-misses as a pedestrian or for being in a near miss as a driver.

A 2012 study by Camden et al. explores the impact of pedestrian countdown signals on pedestrian-motor vehicle collisions in Canada. Using a single group pre-test post-test design, the researchers compare the number and severity of vehicle-pedestrian collisions before and after the installation of pedestrian countdown signals in Toronto. The researchers find no significant effect on any outcomes and conclude that the installation of pedestrian countdown signals is insufficient, by itself, to reduce collisions at intersections.

[12] Pelican pedestrian crossings have traffic lights facing oncoming traffic and illuminated pictograms facing pedestrians from across the road. Puffin crossings are similar but the illuminated pictograms are in the same side of the road as the pedestrian. Furthermore, pelican crossings cannot adjust the all-red clearance time, whereas a puffin crossing can extend this if needed using sensors.

[13] The Hawk consists of two red lights above a yellow light. It is normally dark, but once activated by a pedestrian, it changes from a flashing to a solid yellow, then red for motorists and then provides a WALK message to pedestrians.

[14] Shared lane markings or sharrows are road markings designed to signal that road space should be shared between motorists and cyclists.

Fayish and Gross (2010) employ a comparison at a single point in time between a treatment and comparison group to evaluate the effectiveness of leading pedestrian intervals (LPIs)[15] in the United States. The researchers find that LPIs result in a statistically significant 58.7% reduction in pedestrian–vehicle collisions (95% CI: 46.2, 71.3). Based on the findings, Fayish and Gross conclude that LPIs carry the potential to reduce pedestrian motor vehicle collision and are cost-effective interventions for reducing risk[16].

Street lighting

Porchia et al. (2014) undertake a systematic review of the impact of improving cyclists' visibility on the risk of night time collisions. The review undertakes a narrative synthesis of four studies. The authors find that street lighting can prevent road traffic collisions, injuries and fatalities and can increase pedestrian night-time visibility. Retting et al.'s 2003 literature review also finds evidence that street lighting can reduce risk of pedestrian motor vehicle collision.

Safe routes to school

Orenstein et al. (2007) also investigate the effect of the Safe Route To School (SRTS) in California on collision rates among pedestrians and cyclists aged 5-17. SRTS includes traffic calming measures, improvements to sidewalks, efforts to promote pedestrian and bicycle access, and education on safety. The authors do not find an effect of the programme on collision rates when comparing treatment areas with the control areas. However, the authors state that it is likely that participation rates for walking and cycling decreased in control areas and increased in treatment areas over the relevant time period and when this is accounted for, find that the programme does have an overall effect on reducing collision rates.

Di Maggio et al. (2014) employ a Difference-in-Differences (DID) design to evaluate the US-based Safe Route To School (SRTS) programme in New York. The researchers measure the effect of the programme on reducing the number of pedestrian collisions involving school-aged children during school-travel hours. The researchers find a non-statistically significant 44 per cent reduction (95% CI: 87%, 130%) in school-age pedestrian injury risk during school-travel hours. This demonstrates a positive effect of the programme in reducing the number of pedestrian collisions involving school-aged children.

Another study by Di Maggio et al. (2015) with the same design examines the impact of the Safe Route To School (SRTS) programme on annual rates of pedestrian and cyclist injuries as well as fatalities for school-aged children in Texas. The researchers compare collision data on children (treatment group) and adults (control group), before and after the intervention. The findings show a statistically significant 14 per cent decline in school age injuries (adjusted injury risk ratio [RR] 0.86, 95% CI: 0.75, 0.98). For annual fatality rates, the findings show a 10 per cent reduction among school age fatalities, although this effect is not statistically significant (adjusted IRR 0.90, 95% CI: 0.67 to 1.21).

[15] LPIs provide pedestrians in the United States with 3-7 seconds advance start on motorists when entering an intersection, enforcing their right of way over turning vehicles.
[16] Note that unlike in the US, in the UK the pedestrian phase is normally fully protected.

Note that the effect of safe routes to schools programmes are also discussed in *section 6.2 on law and rules of the road.*

Using a single group pre-test post-test design, Rothman et al. (2015b) evaluate the effectiveness of school crossing guards in Canada (aka school crossing patrol officers) on reducing pedestrian motor vehicle collisions. The authors find no significant change in collision risk following the implementation of a crossing guard (IRR 1.02, 95 % CI: 0.74, 1.40).

Not covered by the evidence base

Measures dealing with right turning cycle traffic (e.g. two-stage right turn) and road maintenance were included as intervention types within the infrastructure and road sign category, but our priority studies for synthesis do not provide any evidence on such interventions.

Summary

Our search recovered 23 studies on infrastructure and road signs interventions that were then prioritised for synthesis.

Traffic calming: A literature review (Reid and Adams 2010) on traffic calming measures such as chicanes, pedestrian refuge islands and systematic approaches (placemaking) finds they can reduce speeds, reduce casualties for all road users and increase rates of levels of cycling. They note that such infrastructure needs to be carefully designed, with some evidence that traffic calming measures can increase numbers of motor vehicle drivers overtaking on approach or cyclists taking evasive behaviour to avoid traffic calming entirely. Two primary studies of speed humps find that they lead to reduced pedestrian collisions (Arbogast et al. 2018) and injuries (Rothman et al. 2015a). One study of speed cameras finds they reduce cyclist and pedestrian injury (De Pauw et al 2014a), while a further study of speed and red light cameras finds a reduction in cyclist injury, but no effect for pedestrians (De Pauw et al 2014b).

Cycle tracks and cycle lanes: The evidence on the effectiveness of cycle tracks and cycle lanes is mixed. A recent Systematic review (Mulvaney et al. 2016) of cycle infrastructure such as cycle lanes and cycle routes and networks containing multiple types of cycle infrastructure finds no significant effect on cyclist collisions and the authors highlight a lack of high quality research. Similarly, findings from a literature review by (DiGioia et al. 2017) on cycle infrastructure including cycle lanes and cycle tracks are also inconclusive regarding collision and injury rates.

However, a literature review (Reynolds et al. 2009) concludes that cycle infrastructure including cycle lanes and tracks reduces the risk of collisions and injuries compared to cycling on-road with traffic or off-road with pedestrians. Reynolds et al. conclude that continental networks perform better than UK ones, possibly because they include physical measures to slow vehicle traffic at intersections with segregated cycle tracks.

A recent literature review (Usami and Amarri 2017), drawing largely on meta-analysis from a single study, concludes that the installation of non-separated cycle lanes leads to a small though non-statistically significant reduction in bicycle accidents, while physically separated cycle tracks can result in an increase in bicycle accidents, particularly at intersections.

However, a rapid evidence assessment (Brook Lyndhurst 2016) finds evidence that segregated cycle tracks can lead to a lower risk of cyclist injury as well as accidents, while coloured bicycle lanes and bicycle phases in traffic signals can be effective in reducing collisions.

A literature review of 23 studies (Thomas and DeRobertis 2013) exploring the effect of cycle tracks that physically separate cyclists from the motorised vehicle traffic concludes that where intersections are well designed - for example by bringing cycle tracks closer to the parallel vehicle traffic at intersection approach to increase cyclist visibility or raising vehicle crossings (like a speed bump) at cycle track intersections - constructing cycle tracks reduces collisions and injuries. Reid and Adams (2010) find little evidence that marked cycle lanes provide benefit on measures of risk for cyclists, but that segregated tracks may reduce risk or severity of collisions for cyclists, although sections where they intersect with roads may offer heightened risk and offset the overall benefit.

Overall, the evidence on cycle lanes and cycle tracks that physically separate cyclists from motor traffic does not provide a clear conclusion regarding their effectiveness. Not all studies clearly differentiate findings for cycle tracks from those for cycle lanes. There is no clear evidence that cycle lanes reduce risk. However, the evidence suggests that physically separated cycle tracks may be more likely to be effective in reducing risk for cyclists than cycle lanes, but cycle track design is vital in determining effectiveness, especially where they intersect with carriageways. Some key features for cycle design at intersections include bringing tracks close to parallel vehicle traffic to increase visibility; raising motor vehicle crossings at intersections; providing advance stop lines for vehicles; and dedicated signals to separate cyclists from turning vehicles.

Advanced stop lines: Thomas and DeRobertis (2013) conclude that advanced stop lines can be an important design feature for effective cycle intersections. However, a literature review (Reid and Adams 2010) and a rapid evidence assessment (Brook-Lyndhurst 2016) find no effect for advance stop lines on risk though the latter study concludes that they may reduce cyclists' perceived risk.

Junctions and roundabouts: A literature review (Soteropoulos and Stadtlbauer 2017) finds that the safety effects of junction conversions to roundabouts depend largely on the type of cyclist infrastructure implemented, with worse outcomes in terms of risk for cycle lanes close to the roadway, but reductions in accident frequency for roundabouts with cycle tracks. Mulvaney et al. (2016) echo this, concluding that conversion of intersections to roundabouts with marked cycle lanes increases cycle collisions, whereas conversion of intersections with and without signals to roundabouts with cycle tracks may reduce risk of collision.

Signal control: A literature review (Kennedy and Sexton 2009) notes the limited evidence base, but tentatively concludes that signalised crossings reduce pedestrian collisions. Other evidence reviews echo this finding by showing that signs and signals can reduce pedestrian-motor vehicle collisions, though evidence from some primary studies indicates that this is not always the case.

Street lighting: Literature reviews by Porchia et al. (2014) and Retting et al. (2003) provide evidence that street lighting can reduce pedestrian vehicle collisions and injuries.

Safe routes to school: Finally, various primary studies find that Safe Route to School programmes implementing traffic calming measures, improvements to sidewalks, efforts to promote pedestrian and bicycle access and education on safety can reduce pedestrian-vehicle collisions and injuries.

Not covered by the evidence base: Our priority studies for synthesis do not include studies on measures dealing with right turning cycle traffic (two-stage right turn) or road maintenance.

6.2 Interventions concerning the law and rules of the road

Interventions concerning the law and rules of the road include those relating to: the Highway Code; road traffic laws, laws concerning mandatory wearing of protective gear such as helmets; stricter civil liability; insurance; speed limits; and enforcement. Fifteen studies evaluating law and rules of the road interventions are included in the REA for synthesis. These include seven evidence reviews (three systematic reviews, three literature reviews, and one rapid evidence assessment) and eight primary studies (one cross-sectional comparison group study, one pre-test post-test, one regression analysis and five interrupted time series studies).

Most of the evidence evaluated law interventions that introduced mandatory helmet use in children, adolescents and adults and examined their impact on risk of injury to cyclists. Two systematic reviews (Olivier and Creighton, 2017; Macpherson and Spinks 2008) and two literature reviews (Clarke 2012; Carrol et al. 2014) are described along with five relatively recent primary studies that examine helmet legislation. A systematic review by Mulvaney et al. (2016), a rapid evidence assessment by Brook Lyndhurst (2016), and a literature review by Reid and Adams (2011) explore the effect of speed limit interventions on risk and perceived risk of injury for cyclists, along with a comparison group study by Ohlin et al. (2017). Brook Lyndhurst (2016) also examines the effect of legislation for safe routes to school. An interrupted time series by Prati (2018) explores the impact of a mandatory visibility aids law and Mader and Zick (2014) conduct a regression analysis examining the impact of state expenditure on highway laws. Only two studies (Clarke 2012 and Carroll et al. 2014) report on both some measure of risk and a measure of participation.

Study findings are described below, grouped by intervention type. Table 7.2 in Appendix 7 provides an overview of the included studies and their findings.

Mandatory Helmet Use Legislation

Macpherson and Spinks (2008) undertake a systematic review of evaluations of bicycle helmet legislation. They include six studies and synthesise them narratively as they were not found to be similar enough to include in a meta-analysis. The authors conclude that helmet legislation appears to be effective in increasing helmet use and decreasing head injury rates. However they note that few high quality studies report on these outcomes.

Carroll et al. (2014) undertake a literature review of a range of literature on mandatory cycle helmet legislation and its impact on the risk of cyclist head injuries and cycling participation. The review synthesises study findings narratively, concluding that mandatory cycle helmet legislation is likely to reduce head related trauma and there is no evidence of an increase in injuries. The review is not able to come to a definitive conclusion regarding the impact of the legislation on cycling participation, finding that, if there is any effect, it is one of a short-term reduction in child cycling participation.

Olivier and Creighton (2017) systematically review 40 studies on the effect of bicycle helmet use. The meta-analysis indicates that helmet interventions produced statistically significant reductions for cyclist head injuries, serious head injuries, facial injuries and fatal head injuries (see findings section 6.5 of this report for a full description of findings).

Regarding helmet legislation specifically, the authors note the finding by Macpherson and Spinks (2008) reported earlier in this section that helmet legislation is effective in increasing helmet use and decreasing head injury rates, but state that later studies have shown more mixed results, with some indicating legislation is effective, has no effect or produces mixed effects by gender.

A literature review by Clarke (2012) examines the impact of the 1994 New Zealand Helmet Law on the risk of injury rates per hour for cyclists and the impact on cycling participation. The review narratively synthesises seven studies, concluding that the studies typically indicate that the helmet law failed to promote cycling, safety and health. They conclude that the legislation led to a reduction in bicycle usage and an increase in cyclist injury risk.

In addition to the evidence from evidence reviews, we also found several studies published after Macpherson and Spinks' (2008) systematic review. Wesson et al. (2008) undertake an interrupted time series study to explore the impact of mandatory helmet legislation aimed at two age groups (1–15 year-olds and 16 years and above in the USA). The study finds a statistically significant reduction in the risk of bicycle-related deaths amongst 1-15 year-olds. The number of bicycle-related deaths decreased by 0.59 deaths per month post-legislation (95% CI: 0.29, 0.89). For cyclists 16 years and above, there was no significant change (0.09, 95% CI: -0.35, 0.53), a difference the authors do not comment on.

An interrupted time series study by Walter et al. (2011) evaluates the impact of mandatory helmet legislation on cyclists in Australia. The authors find a statistically significant reduction in the risk of head injury admissions for cyclists, with the number of admissions for cyclists decreasing by 7.5% ($p < 0.005$) in the 18 month period post-legislation.

Dennis et al. (2013) conduct an interrupted time series study examining the impact of introducing mandatory helmet legislation aimed at under-18 year-olds in six provinces of Canada. The study did not detect an effect for legislation on the rate of hospital admissions for cycling related head injuries.

Bonander and Andersson (2014) undertake an interrupted time series study investigating the impact of a new Swedish bicycle helmet law for children under the age of 15. Analysis comparing the difference between the intervention effect estimates for children and a control group of adults finds a statistically significant reduction in the risk of head injuries from bicycle collisions amongst male children below 15 years old equivalent to 7.8 percentage points (OR = 0.68, 95% CI: 0.75, 1.031]). They find no significant effect for female children under 15 years old. The authors are unable to explain this difference between boys and girls.

Finally, a single group pre-test post-test study by Karkhaneh et al. (2013) in Canada explores the impact of mandatory helmet legislation introduced in 2002 across three age groups; children below 13, adolescents aged 13-17 years and adults 18 years and above. The study finds a statistically significant reduction in the risk of bicycle related head injuries amongst children below 13 (adjusted proportion ratio = 0.70, 95% CI: 0.55, 0.90). After adjusting for sex and location, the study also finds a statistically significant reduction in the risk of bicycle related head injuries amongst adolescents aged 13-17 years (APR = 0.64, 95% CI: 0.49, 0.84), and adults (APR = 0.76, 95% CI: 0.63, 0.91).

Note that we discuss helmets in several places in this review, including a discussion of the effects of education regarding helmet wearing in section *6.3 on training and testing interventions* and in *section 6.5 on vehicles and equipment*.

Implementation of Speed Limits

A systematic review by Mulvaney et al. (2016) conducts a narrative review and concludes that 20mph speed restrictions in urban areas may (they are able to find only a small number of studies) reduce cyclist collisions.

Brook Lyndhurst (2016) conducts a rapid evidence assessment on walking and cycling safety interventions. The review finds a small evidence base and tentatively concludes that speed limits such as 20 mph can lead to reduced numbers of cyclist casualties and increased participation.

A literature review by Reid and Adams (2011) reviews the impact of interventions to promote cycle safety on the risk of cycle casualties. The review includes 33 studies in a narrative synthesis, though this is for a range of interventions including 20mph speed restrictions and traffic calming. The authors conclude that there is strong evidence that speed restrictions can result in reduced numbers of casualties for all road users and a reduction in severity of casualties for cyclists.

A cross-sectional comparison group study by Ohlin et al. (2017) in Sweden investigates the impact of speed limit reductions on pedestrian and cyclist injuries. The researchers collected injury data and classified an injury by the STRADA injury severity scale[17]. The study finds that speed limit reductions to 40kmh (approx. 25 mph) reduce the injury risk for pedestrians and cyclists, though only effects for a small number of types of STRADA injury severity categories for cyclists are statistically significant.

Cyclist Visibility Legislation

A recent interrupted time series study by Prati (2018) explores the impact of a mandatory visibility aids law on the number of bicycles involved in road collisions in Italy[18]. Results indicate no evidence of an effect immediately after legislation was introduced on the number of bicycles involved in road collisions ($\beta = -8.51$, $p = 0.939$ [95% CI: −229.02, 212.01]). Furthermore, no evidence of an effect over time was found ($\beta = -0.25$, $p = 0.921$ [95% CI: −5.25, 4.75]). The authors note that a lack of knowledge regarding how the law was implemented or enforced or what behavioural responses there were makes it difficult to explain the lack of an effect.

[17] STRADA classifies injuries according to the Abbreviated Injury Scale (AIS). AIS classifies injuries by body region according to relative importance on a 1–6 point ordinal scale, where 1 = minimum and 6 = maximum.
[18] The law requires cyclists to wear high-visibility clothing in addition to (and not in replacement of) bicycle lights when riding after dusk and before dawn.

Note that we discuss cyclist visibility clothing more generally (i.e. where not covered by legislation) in *section 6.5 on vehicles and equipment*.

Expenditure on highway law enforcement

Mader and Zick (2014) conduct a regression analysis exploring the impact of state expenditure on highway law enforcement and other safety expenditures such as graduated driver licence[19] regulations, bike helmet regulations and other regulations such as driver blood alcohol concentration regulations in the United States. The authors find that non-motorist fatalities are reduced by increased state highway law enforcement and safety expenditures per capita.

Safe routes to schools legislation

Brook Lyndhurst's (2016) rapid evidence assessment of walking and cycling safety interventions finds evidence of a reduction in child casualty rates for safe routes to schools legislation which required routes to school to be made safe via measures such as traffic calming and safety education.

Note that the effect of safe routes to schools programmes are also discussed in *section 6.1 on infrastructure and road signs.*

Interventions not covered by the evidence

None of the priority studies included for synthesis provide evidence on law interventions focusing on civil liability, insurance, or road traffic laws that focused on turn left on red (though section 6.1 does cover signal control for turning on red), 'give way on turn' rules, and no overtaking of cyclists on cycle streets.

Summary

Our search recovered fifteen studies on interventions concerning law and rules of the road that were then prioritised for synthesis.

Mandatory Helmet Use Legislation: A systematic review of evaluations of bicycle legislation (Macpherson and Spinks 2008) synthesises six studies and concludes that there are few high quality studies, but that helmet legislation appears to be effective in increasing helmet use and decreasing head injury rates. A literature review (Carroll et al. 2014) also concludes that helmet legislation is likely to reduce head related trauma and that it may not impact cycling participation, although a temporary reduction in child cycling participation was observed in some studies. However, a literature review by Clarke (2012) reviews seven studies on the 1994 New Zealand Helmet Law and finds studies typically indicate that the helmet law had a negative impact on bicycle usage and an increase in cyclist injury risk.

[19] Graduated driver licenses guide new drivers through several stages through which they typically first gain a learner's permit, gain a probationary license, and then full license.

Olivier and Creighton (2017) note the earlier finding by Macpherson and Spinks (2008) that helmet legislation is beneficial, but state that later studies have found mixed results, with some indicating legislation is effective, has no effect or produces mixed effects by gender. This conclusion is also supported by the more recent primary studies included in this rapid evidence assessment. Thus overall, while there are studies that find helmet legislation can be effective in reducing cycle injuries, some studies find no effect or even a negative effect (as in Clarke 2012). Only two studies look at participation. One literature review indicates the difficulty of coming to firm conclusions but that, if there is any effect, it is one of a short-term reduction in child cycling participation (Carroll et al. 2014). The other indicates that helmet legislation in New Zealand reduced cycling participation (Clarke 2012)

Implementation of Speed Limits: A systematic review (Mulvaney et al. 2016), a rapid evidence assessment (Brook-Lyndhurst 2016) and a literature review (Reid and Adams 2011) all find evidence that speed restrictions (typically of 20mph) are effective in reducing cyclist collisions or casualties. Brook-Lyndhurst (2016) also finds that they can lead to increased participation.

Cyclist Visibility Legislation: A primary study of cyclist visibility legislation in Italy (Prati 2018) finds no effect on bicycle road collisions.

Expenditure on highway law enforcement: A further primary study (Mader and Zick 2014) finds that state expenditure on highway law enforcement and other interventions reduces non-motorist fatalities.

Safe routes to schools legislation: Finally, a rapid evidence assessment (Brook-Lyndhurst 2016) finds evidence of a reduction in child casualty rates for safe routes to schools legislation.

Not covered by the evidence base: None of the priority studies that we include for synthesis report on interventions relating to law or rules of the road that focus on civil liability and insurance or road traffic laws that focused on turn left on red, ‘give way on turn’ rules and no overtaking of cyclists on cycle streets.

6.3 Training and testing interventions

Training and testing interventions include practical training and obtaining and maintaining driving qualifications; training for motorists; training in cycle safety or safe road crossing.

Five studies on training and testing interventions are included in the REA for synthesis. Three of the included studies consider training and testing interventions targeted exclusively at children or young people. One systematic review investigates studies of behavioural interventions to promote safe road crossing such as classroom or computer-based training (Schwebel et al. 2014) while the second examines community-based interventions to prevent pedestrian injuries (Turner et al. 2004). A third systematic review reports on studies of bicycle skills training programmes (Richmond et al. 2014), along with two primary studies by Ducheyne et al. (2014) and by Hodgson and Worth (2015). All five studies report some measure of risk or perceived risk, but only one reports on participation (Ducheyne et al. 2014).

Study findings are described below, grouped by intervention type. Table 7.3 in Appendix 7 provides an overview of the included studies and their findings.

Training in safe use of roads for pedestrians

A 2014 systematic review by Schwebel et al. includes 19 papers (covering 25 studies) on behavioural interventions teaching road safety to children aged 3-11. Interventions include one-to-one or small-group training, classroom training, computer-based or virtual reality training, board games, peer-group activities, and videos. The authors undertake various meta-analyses to synthesise study findings. They include studies reporting any measure of pedestrian safety behaviour (crossing at mid-block[20] locations, crossing at junctions, crossing between parked cars, preventing 'dash-out'[21] crossings, judging the speed of oncoming traffic, and selecting safe routes to cross). The authors undertake separate meta-analyses for studies reporting continuous or dichotomous outcomes and for studies reporting the effect on outcomes immediately after the intervention or at follow-up a few months later.

A meta-analysis of ten studies reporting the effect of behavioural interventions on continuous measures of pedestrian safety behaviours indicates a statistically significant increase in safety (standardised mean difference = 0.31, 95% CI: 0.12, 0.50), as does a further meta-analysis of 15 studies reporting effects on dichotomous measures of pedestrian safety behaviours (RR = 3.44, 95% CI: 2.05, 5.75). Results at follow-up indicate a smaller but no longer statistically significant increase in safety behaviours for a meta-analysis of five studies reporting continuous outcomes (SMD = 0.17, 95% CI: 0.00–0.34) and a statistically significant increase in safety for a meta-analysis of eight studies reporting dichotomous outcomes (RR = 2.88, 95% CI: 1.89, 4.39).

[20] A 'block' is any urban or suburban area bounded by four streets.
[21] Where children enter carriageways without stopping to select a safe route before crossing

Overall the authors conclude that programmes are effective in increasing safe behaviours immediately after an intervention and, to a reduced degree, at follow-up. They also explore whether particular types of interventions were relatively more effective and conclude that one-on-one or small-group training strategies are effective while other types of interventions show mixed results.

A 2004 systematic review of community-based interventions to prevent pedestrian injuries in under 14s (Turner et al.) includes four studies. To be included, studies had to evaluate the effect of interventions involving more than a single strategy for child injury prevention and target a whole community or group of individuals. One study assesses the effect of a combination of community interventions in a single community while the other three explore the effect of community-based injury prevention programmes. Typical strategy components include education for children and parents, new infrastructure and speed limits.

Analysing pedestrian injury rates, or pedestrian/vehicle driver behaviour modification, the review finds a reduction in risk to pedestrians across the four programmes. Three studies find 12%, 45% and 54% reductions in child pedestrian injuries, and the fourth study showing a 9% reduction in traffic flow following behavioural interventions for vehicle drivers at child pedestrian sites (statistical significance not reported). The fourth study also highlights the growth of sustainable community safety promotion activity (not defined in study). The authors note the small evidence base, but tentatively conclude that community-based interventions can be effective in reducing pedestrian injury rates and that more complex programmes involving multiple strategies are likely to be more effective.

Bicycle skills and safety training

A 2014 systematic review includes 25 studies exploring the effectiveness of bicycle skills training programmes in reducing bicycle-related injuries for children under 19 years of age (Richmond et al.) Due to the heterogeneity of study designs and interventions, the authors are unable to undertake a meta-analysis and synthesise included studies narratively. The review finds a lack of high quality research on this type of programme. It concludes that bicycle skills training programmes can increase knowledge of cycling safety, but that this does not appear to translate into any decrease in injury rate. No studies reporting on risk find a statistically significant change (regarding injury frequency and severity, safe cycling behaviour and attitudes) following training programmes.

A randomised controlled trial in Belgium in 2014 (Ducheyne et al.) explores the effect of a cycling training course implemented across three school sites for children aged 9-10. One site acted as a control group where no intervention was implemented, whilst the two remaining sites executed ‘intervention’ and ‘intervention plus parent attending’ programmes. The intervention had an impact on children’s cycling proficiency but did not have a significant effect on how frequently children cycled to school (minutes/week) ($F = 1.9$, $p > 0.05$) or on parental perceived risk of their children cycling.

Finally, Hodgson and Worth (2015) conduct a study with children aged 9-10 years old that participated in a training programme to improve awareness of cycling hazards, to impart road position skills when cycling and to provide a positive engagement with cycling. The study used multilevel regression modelling as its main method. 668 children where involved at 29 schools and followed for a single academic year. The treatment group participated in the Bikeability training intervention for the duration of the summer term. The comparison group did not receive training. The two groups were then assessed with an on-screen quiz to test knowledge and skills relating to hazard perception and response. The findings showed a statistically significant increase in the treatment group's ability to perceive hazards and respond appropriately (effect size 1.58) and road positioning skills (effect size 0.24). Furthermore, the treatment group had a statistically significant increased confidence in cycling (effect size 0.53) measured via response to a questionnaire on a scale from 1 = 'not at all confident' to 4 = 'very confident'.

Not covered by the evidence base

Our priority studies for synthesis do not provide any evidence on interventions related to obtaining and maintaining driving qualifications or training for motorists. This is in part due to the fact that studies on, for example, driver's license interventions often focus on outcomes for drivers themselves rather than those for pedestrians or cyclists. Secondly, none of the included studies consider training and testing interventions targeted at adults.

Summary

Our search recovered only a limited evidence base of studies relating to training and testing interventions that met our inclusion criteria and only five studies were prioritised for synthesis.

Training in safe use of roads for pedestrians: Evidence from a systematic review and meta-analysis (Schwebel et al. 2014) of behavioural interventions targeting 3-11 year olds such as classroom training, indicates that this type of programme can increase pedestrian safety behaviours, though these increases are smaller at follow-up a few months later. Individual or small-group training strategies are found to be more effective than others. A systematic review (Turner et al. 2004) of interventions employing multiple strategies to reach a whole community recovers only a small evidence base but reaches the tentative conclusion that such programmes can reduce pedestrian injury rates.

Bicycle skills and safety training: A systematic review (Richmond et al. 2014) of bicycle skills training programmes found that although programmes may increase cycling proficiency, this does not appear to translate into reduced risk of injury. Some recent primary studies support this conclusion, although findings from one study indicate that training can improve safe cycling behaviours.

Not covered by the evidence base: Our priority studies for synthesis do not include studies of interventions related to obtaining and maintaining driving qualifications or training for motorists.

6.4 Road user education interventions

Road user education interventions include education campaigns via schools, media or other settings, or as part of rehabilitations schemes or communication campaigns through government initiatives. Four studies evaluating road user education interventions are included in the REA for synthesis. Of the four included studies, we found one systematic review, one randomised controlled trial, one interrupted time series study and one single group pre-test post-test. The systematic review explores evidence on the effectiveness of correct bicycle helmet use education for children (Lee et al. 2009). The primary studies explore an online education campaign (Gamble et al. 2015), a project educating pedestrians and road users on danger perception at high risk crossings (Zegeer et al. 2008) and an evaluation of the THINK! poster campaign to provide tips for cyclists and motorists (TNS BRMB 2015). All included studies report some measure of risk or perceived risk but only one explores participation (Gamble et al. 2015).

The following section reports on these studies, grouping them by intervention type where relevant. Table 7.4 in Appendix 7 summarises study settings, methodologies and outcomes.

School based education on correct bicycle helmet use

A 2009 systematic review of evidence from North America and Australia (Lee et al.) explores the impact of helmet fit on the risk of head injury on children, but it also explores the effect of school-based educational programmes to increase the prevalence of correct helmet use among schoolchildren. Educational elements included strategies such as involving use of educational resources, how to wear a helmet correctly and peer led discussion of helmet use. Only a single included study reports the impact of helmet fit on the risk of head injury on children, reporting a significant reduction in head injuries for those wearing excellent fitting helmets compared those with a poor fit. School-based educational programmes appear to be effective in promoting correct helmet use among schoolchildren.

Note that we discuss helmets in several places in this review, including a discussion of the effects of helmet wearing in *section 6.5 on vehicles and equipment* and a discussion the effectiveness of laws regarding helmet wearing in section *6.2 on law and rules of the road*.

Education campaigns

A 2008 study used interrupted time series to evaluate the impact of a programme in Florida's Miami-Dade county involving educating pedestrians via workshops, leaflets, videos, training police officers in pedestrian safety and enforcement, and investment on infrastructure such as pedestrian warning signs or traffic islands (Zegeer et al). The evaluation finds a 13.3% reduction in pedestrian collisions with a similarly sized neighbouring county used as a control, and 8.5% reduction when using six metropolitan counties or the state-wide pedestrian collision rates as control. All findings are statistically significant at the 0.05 level.

A 2015 study by Gamble et al. of a cycling education campaign involved an online randomised controlled trial, where 228 cyclist and non-cyclists were randomly allocated to groups to read either health-focused, safety-focused or control group publications.

Participants were asked to complete a questionnaire before and after reading any publications. No statistically significant effects were noted for any group on perceived risk for cyclist and non-cyclists. No statistically significant effects were found on participants’ intentions to cycle.

A 2015 study by TNS BRMB evaluates the THINK! poster campaign in the UK providing road safety tips for cyclists and motorists. The study uses a single group pre-test post-test design to evaluate the effect of the campaign, with the authors finding that claimed safe cycling behaviours such as stopping at red lights or cycling in the middle of the road when on narrow streets increased. There was little change in motor vehicle driver claimed safety behaviours such as leaving cyclists room on the road.

Not covered by the evidence base

None of the studies prioritised for synthesis provide evidence on rehabilitation schemes such as national speed awareness courses. Typically interventions focus on educating cyclists rather than drivers.

Summary

Our search recovered only a limited evidence base of studies relating to road user education interventions that met our inclusion criteria and only four studies were prioritised for synthesis.

School based education: A systematic review (Lee et al. 2009) finds limited evidence that can say anything regarding the effectiveness of education interventions. A single study indicates that school-based education programmes can promote correct helmet usage.

Education campaigns: A primary study (Zegeer et al. 2008) of a pedestrian education campaign at high-risk crossings finds a reduction in pedestrian collisions. A 2015 study by TNS BRMB finds that the THINK! poster campaign led to an increase in claimed safe cycling behaviours, but had no effect on claimed safe motor-vehicle driving behaviours. A further primary study (Gamble et al. 2015) finds that an online education campaign for cyclists did not have an effect on perceived risk or intentions to cycle.

Overall, we did not find much evidence to enable any firm conclusions to be drawn as to the effectiveness of education. None of the studies prioritised for synthesis reported on interventions as part of rehabilitation schemes such as national speed awareness courses.

6.5 Vehicle and equipment interventions

This category of intervention includes both vehicle interventions and equipment interventions. Vehicle interventions include standards for new motor vehicles and bicycles; vehicle maintenance; and safety features of motor vehicles. Equipment interventions include bicycle helmets, equipment to improve cyclist and pedestrian visibility, and cycle hire/ bikeshare. In all, twelve studies on vehicle and equipment interventions are included in the REA for synthesis. The included studies comprise eight evidence reviews (three systematic reviews, one rapid evidence assessment and four literature reviews), two randomised controlled trials, and one cross-sectional comparison study.

For vehicle-related evidence, a literature review (Saadé 2017), a regression modelling study (Silla et al. 2017) and a cross-sectional comparison group study (Ohlin et al. 2017) look at safety features of motor vehicles. Regarding equipment-related interventions, four evidence reviews (Carrol et al. 2014; Hynd et al. 2009; Lee et al. 2009; Olivier and Creighton 2017), explore helmet use, while two evidence reviews (Kwan and Mapstone 2006; Reed 2017) and two RCTs (Lahrmann et al. 2017; Madsen et al 2013) examine equipment to improve cyclist and pedestrian visibility, such as high visibility clothing and bike lights. A single synthesis study looks at cycle hire bikes (Brook Lyndhurst 2016). The latter is also the only study that reports outcomes related to participation.

Study findings are described below, grouped by intervention type. Table 7.5 in Appendix 7 provides an overview of the included studies and their findings.

Standards and safety features of motor vehicles

In a literature review of six studies, Saadé (2017) investigates the effects of autonomous emergency braking (AEB) in motorised vehicles, on risk to both cyclists and pedestrians. Most included studies consist of prospective analyses through simulations, with only one study comprising a retrospective analysis. The authors report that AEB reduces the number and severity of pedestrian and cyclist accidents.

A cross-sectional comparison group study by Ohlin et al. (2017) uses emergency hospital reports to measure the impact of the European New Car Assessment Programme (Euro NCAP)[22] .rating on pedestrian and cyclist injury severity. The researchers collected injury data and classified an injury by the STRADA injury severity scale[23]. The study reports a 56% difference between low and highly rated cars in the risk of permanent medical impairment of pedestrians (p-value 0.002), and a 26% difference for cyclists (p-value 0.036). For cyclists, the impacts on specific injury types are also measured. Differences of 50%, 45% and 54% (p-values 0.015, 0.028, 0.000) are reported in risk of permanent medical injuries to the head, lower extremities and other areas respectively. There is also a difference in injuries of Accident Injury Severity 2 and above, of 83% for head injuries and 49 for other injuries (p-values 0.000 and 0.000 respectively).

[22] Which provides consumer information on the safety of new cars
[23] Maximum abbreviated injury scale (MAIS), Abbreviated injury scale (AIS): 1 = minor, 2 = moderate, 3 = serious, 4 = severe, 5 = critical, 6 = maximum

Silla et al. (2017) evaluate 5 intelligent transport systems designed to improve cyclist safety, measured through cyclist fatalities and injuries. The systems include: vehicle sensor Blind Spot Detection (BSD); Bicycle to Vehicle communication (B2V), which informs drivers regarding the presence of any riders in the vicinity; Intersection safety (INS), whereby roadside units detect the presence of Vulnerable Road Users (VRUs) and collision risks and advises drivers via an on-vehicle unit; Pedestrian and Cyclist Detection System + Emergency Braking (PCDS + EBR); and VRU Beacon Systems (VBS), which are carried by VRUs to alert cars. Using regression modelling, the researchers analyse accident numbers from all 28 EU member states from 2002 to 2012 to forecast accident numbers in 2020 and 2030. The researchers find reductions in cyclist fatalities and injuries for all systems. The highest safety effects can be achieved by implementing PCDS + EBR and B2V. In contrast, VBS has the lowest effect.

Bicycle helmets

Note that we discuss cycle helmets in several places in this REA. In this section we discuss the effectiveness of using cycle helmets, while evidence regarding the effectiveness of cycle helmet legislation is in *section 6.2 on law and rules of the road*, and a discussion of cycle helmet education is in *section 6.3 on training and testing.*

A systematic review by Olivier and Creighton (2017) finds 43 studies on the impact of bicycle helmet use on different types of head injury and includes 40 of them in meta-analyses. Results of the meta-analysis indicate that helmet use is associated with a 51% reduction in the odds of head injury (odds ratio (OR): 0.49, 95% CI: 0.42, 0.57), a 69% reduction in serious head injury (OR 0.31, 95% CI: 0.25, 0.37), a 33% reduction in facial injury (OR 0.67, 95% CI: 0.56, 0.81), and 65% reduction in fatal head injury (OR 0.35, 95% CI: 0.14, 0.88).

Hynd et al. (2009) carry out a literature review and include 20 hospital admissions and population-level studies in their narrative synthesis. They report that most hospital admissions studies (typically case-control) find that helmets are effective in reducing head injuries, whereas population-based studies (typically longitudinal) show little to no effect. The authors also note the limitations of the evidence base, in particular, appropriateness of control groups to fully control for confounding factors that may explain behavioural differences between treatment and control groups (e.g. people who wear helmets may be more likely to cycle safely). Carrol et al. (2014) update the review by Hynd et al. (2009). The authors conclude that helmet wearers involved in collisions suffer fewer injuries than unhelmeted cyclists.

A systematic review by Lee et al. (2009), reviews 11 studies exploring correct bicycle helmet use. Only one of these measures the impact of helmet fit on the risk of head injury on children, reporting a significant reduction in head injuries for those wearing excellent fitting helmets compared those with a poor fit.

Equipment to improve cyclist and pedestrian visibility

A large systematic review finds 42 randomised controlled trials and controlled before-and-after studies exploring the effect of reflective garments, flashing lights, and other visibility aids on a range of outcomes including drivers' ability to detect pedestrians and cyclists earlier (Kwan and Mapstone 2006). However, the review finds no studies that report on the effect of visibility aids on the occurrence of pedestrian and cyclist/motor collisions, indicating the lack of evidence at time of writing. The review concludes that visibility aids can improve drivers' detection and recognition responses.

Reed (2017) conducts a literature review on the effectiveness of cyclist protective clothing in the form of high visibility clothing. The review includes five studies, and reports that wearing high visibility clothing reduces the risk of collision involvement and the amount of time off work due to injuries after collisions.

Two Danish RCTs investigate the safety impacts of equipment to improve the visibility of vulnerable road users. A study by Madsen et al. (2013) evaluates the use of permanent bicycle mounted lights. The study finds a statistically significant 19% decrease in all bicycle accidents (solo and multiparty) (incidence rate ratio = 0.81, 95% CI: 0.61, 1.09), and a statistically significant 47% decrease in multiparty accidents with personal injury (IRR = 0.53, 95% CI 0.31-0.91).

Another RCT in Denmark, by Lahrmann et al. (2017) investigates the impact of a yellow high visibility jacket for cyclists on self-reported accidents. The authors find a statistically significant 38% decrease in self-reported multiparty accident rate ratio for personal injury accidents involving cyclists (accident rate ratio = 0.62, 95% CI: 0.39, 1.00), after controlling for response bias.

Note that we discuss cyclist visibility legislation in *section 6.2 on law and rules of the road.*

Cycle hire / bikeshare

A rapid evidence assessment (Brook Lyndhurst 2016) considers interventions to increase participation in cycling and walking. The authors find some evidence from econometric evaluations of bikeshare schemes showing they can lead to fewer injuries and mortalities than normal bikes. This may be because they are slower, have built-in lights, fewer bikeshare trips are made on roads or because drivers are more careful around hire cycles. They also find that schemes can increase the number of bicycle trips.

Not covered by the evidence base

Our priority studies for synthesis do not provide evidence on the standards for, or maintenance of, bicycles or motor vehicles.

Summary

Our search recovered a reasonable body of evidence on the effectiveness of vehicle and equipment interventions and twelve studies were prioritised for synthesis.

Standards and safety features of motor vehicles: A literature review (Saade 2017) of six studies finds that autonomous emergency braking in motorised vehicles reduces the number and severity of pedestrian and cyclist accidents. There is also evidence from primary studies that the New Car Assessment Programme (Euro NCAP) rating (Ohlin et al. 2017) can decrease pedestrian and cyclist injury severity, while intelligent transport systems (Silla et al. 2017) can reduce cyclist fatalities and injuries.

Cycle helmets: A recent systematic review and meta-analysis by Olivier and Creighton (2017) provides clear evidence that helmet use reduces the odds of injury and the seriousness of head injuries.

Equipment to improve cyclist and pedestrian visibility: A large systematic review from 2006 (Kwan and Mapstone) synthesises 42 studies on the effect of visibility clothing for cyclists but found none that report on their effect on collisions, indicating the lack of evidence at time of publication. However, a more recent literature review (Reed 2017) finds five studies and concludes that evidence that high visibility clothing reduces the risk of collision involvement and the amount of time off work due to injuries after collisions. This conclusion is reinforced by two recent RCTs that find that bicycle mounted lights (Madsen et al. 2013) and Lahrmann et al. (2017) can reduce accidents.

Cycle hire / bikeshare: There is also some evidence from a rapid evidence assessment (Brook-Lyndhurst 2016) that bikeshare schemes can reduce cyclist injuries and mortalities and increase participation.

Not covered by the evidence base: Our priority studies for synthesis do not provide evidence on the standards, safety features or maintenance for bicycles, or motor vehicles.

7 Discussion and conclusions

The following section provides a discussion of the overall completeness and quality of the evidence and of the limitations of the REA process, and then offers some conclusions.

Overall quality and completeness of the evidence

The interventions covered by this REA all work in different ways. Some aim to eliminate some forms of risk, as with cycle tracks that physically separate cyclists from the carriageway. Some aim to mitigate risk, for example through training and education, while others deal with latent risk, for example by equipping cyclists with helmets. The relative effectiveness of the different interventions should be considered within this hierarchy with some interventions capable of eliminating some forms of risk while others only capable of risk mitigation.

The quality of the evidence reviews included in this review is variable. There are a significant number of systematic reviews that aim to comprehensively find and synthesise a body of evidence. However, some other forms of evidence reviews are less rigorous and are not explicit about their search strategy, inclusion criteria or the quality of the evidence they review.

Many of the reviews included in this rapid evidence assessment note the lack of high quality primary studies. Typically, the available evidence base is largely made up of studies that are unable to address potential confounding factors[24]. Implementing high quality studies that can adequately deal with confounding can be particularly difficult and costly within the transport sector.

To be included in our review, studies had to report on the effect of interventions on risk or perceived risk to cyclists or pedestrians. The vast majority of studies that report on these outcomes do not report on the effect of programmes on cycling or walking participation. In fact, only five of our included studies reported on both some measure of risk or perceived risk and on participation in cycling or walking activities. As a result, based on the evidence available, it is difficult to assess whether any observed reduced risk could be offset by (or the result of) reduced participation.

Furthermore, given the need for studies to report on risk or perceived risk *to cyclists or pedestrians* in order to be included, the review excludes evidence reporting solely on motor-vehicle collisions. As interventions targeted at motor vehicles tend to focus on motor-vehicle collisions only, this means the review's focus is on pedestrian and cyclist focussed interventions, rather than those that target drivers of motor-vehicles.

A large number of included studies are evidence reviews that cover multiple settings and interventions. We also included recent primary studies including a limited number of

[24] Confounding may occur when the effect, or the association between a programme and an outcome of interest, is distorted by the presence of another variable. Some study designs are better equipped to deal with possible sources of bias than others.

European primary studies which were complemented by relevant primary studies from America and Australasia.

Although the prioritisation process was intended to ensure that evidence for all intervention categories was synthesised by the REA, some categories are far better evidenced than others. In part, this reflects the fact that the categories themselves are not equal in size – for example, the 'infrastructure and road signs category' covers a larger number of intervention types than the other categories. However, this is also a reflection of the pattern of available evidence, with some intervention types better evidenced than others. Overall, there were more included studies for infrastructure and road signs (number taken forwards for synthesis=23), interventions concerning the law and rules of the road (n=15) and vehicle and equipment interventions (n=12) than for training and testing (n=5) and road user education (n=4) interventions.

For a number of intervention types, we were unable to find any includable studies among the prioritised studies for synthesis: our review does not include studies on the following: measures dealing with right turning cycle traffic (e.g. two-stage right turn), law interventions focusing on civil liability, insurance, or road traffic laws that focused on turn left on red, 'give way on turn' rules, and no overtaking of cyclists on cycle streets, interventions related to obtaining and maintaining driving qualifications or training for motorists, rehabilitation schemes such as national speed awareness courses, standards for new bicycles, standards or maintenance of motor vehicles and bicycles.

Given the rapid nature of this evidence assessment and the need to focus on a limited sub-section of the included evidence base for synthesis, we cannot conclude for these categories that there is no relevant evidence. However, we can conclude that there is unlikely to be a substantial number of relevant studies. Future studies may want to explore some of the intervention types listed above.

Limitations in the review process

This research project adopted an REA methodology that was designed to efficiently locate and synthesise a body of relevant literature. Only a proportion of all hits returned from our search of academic databases were screened, though results were prioritised using machine learning to ensure that the most relevant were assessed for inclusion. Inclusion decisions at title and abstract were also undertaken by only a single reviewer. This means that it is possible that some relevant studies may have been missed. Due to the need for an efficient review process, we also only synthesise a proportion of the studies meeting our inclusion criteria. The findings section and review conclusions are therefore based on a proportion of all includable studies and do not comprehensively summarise all relevant evidence. Studies were prioritised for synthesis based on relevance (see section on methodology). A full list of studies meeting inclusion criteria but not synthesised is provided in Appendix 8.

Authors' conclusions

Overall, there is evidence backed by one or more reviews or multiple primary studies that indicate several types of intervention can reduce risk for cyclists and pedestrians. These include traffic calming measures such as road (or speed) humps, speed cameras, speed restrictions (typically evidence relates to 20 mph limits), street lighting, safe routes to school, behavioural interventions to improve safety practices, vehicle standards and safety measures, cycle helmets and visibility clothing and equipment.

There is also a set of interventions for which the evidence is more mixed. Overall, the evidence on cycle lanes and on cycle tracks that physically separate cyclists from motor traffic is inconclusive. There is no clear evidence that cycle lanes reduce risk, but the evidence suggests that physically separated cycle tracks may be more likely to be effective in reducing risk, but that cycle track design is vital in determining effectiveness, especially at intersections. Some key features for cycle design at intersections include bringing tracks close to parallel vehicle traffic to increase visibility; raising motor vehicle crossings at intersections; providing advance stop lines for vehicles; and dedicated signals to separate cyclists from turning vehicles.

Conversion of intersections to roundabouts with marked cycle lanes may increase cycle collisions, whereas conversion to roundabouts with cycle tracks may reduce risk of collision. There is evidence from various evidence reviews that helmet legislation can reduce head injuries, but more recent reviews and primary studies indicate mixed findings.

Very few studies report on both risk or perceived risk and participation. There is likely to be a far larger literature that looks at the effect of this type of intervention on cycling or walking participation, but clearly few studies examine both this and the question of impact on risk. One important finding regarding participation is that for cycling helmet legislation, one literature review indicates the difficulty of coming to firm conclusions on this question but that, if there is any effect, it is one of a short-term reduction in child cycling participation. A second literature review reports that helmet legislation in New Zealand reduced cycling participation.

Many of the cycling and walking interventions covered in this rapid evidence assessment show promise for reducing risk or perceived risk for cyclists and pedestrians. However, there is a lack of well-designed evaluations that adequately control for bias and also a lack of evidence that explores impact on both risk and participation.

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The following is a list of the references cited in the main body of the text. See Appendices 6 and 8 for lists of studies included in the REA.

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Appendix 1: Methodology

Criteria for including studies in the review

We included both published and unpublished (grey) literature. Detailed criteria for determining inclusion in the REA are listed below.

Types of study designs

Includable experimental and quasi-experimental designs included randomised controlled trials[25], regression discontinuity designs, natural experiments and instrumental variable estimation, and studies with pre and post-intervention outcomes data for an intervention and comparison groups that control for confounding through statistical matching, difference-in-differences (DID) or controlled before-after[26] (or fixed- or random-effects models with an interaction term between time and intervention for baseline and follow-up observations) and interrupted time series[27]. We also included other quantitative methods that rely on correlation or association (single group pre-test post-test[28], cross-sectional comparison studies[29] or regression). Finally, we included evidence reviews (systematic reviews, rapid reviews, rapid evidence appraisals, meta-analyses) that focus on our interventions and outcomes of interest.

Types of participants

This review did not determine inclusion/exclusion according to participant criteria.

Types of interventions

The review included studies that describe one or more of the five intervention types set out below:

a. **Infrastructure and road sign interventions.** These included management of infrastructure and traffic signing (by local authority, government departments e.g. Highways England; regional transport bodies, e.g. TfL and Transport for Greater Manchester); traffic calming measures (e.g. road or speed humps, chicanes, road narrowing); measures to reduce impact of motor traffic (e.g. shared space, pedestrian priority, informal streets and zones de rencontre, home zones and quiet lanes); road building and maintenance (for strategic and local roads; priority junctions (e.g. orientation of priority, geometrical considerations, visibility, crossing side roads; building and maintenance of pavements and cycle track/lanes/streets (e.g. surfacing, ironworks, kerbs and edgings, lighting); road

[25] In an RCT, participants are randomly allocated to treatment or control groups and then outcomes compared.
[26] DID compares the average change over time in the outcome variable for the treatment group, compared to the average change over time for the control group. CBA are similar, comparing outcomes before and after a treatment, for both the treatment and comparison group
[27] Studies that assess changes in trends in outcomes over a series of time points
[28] Compares a single group before and after a treatment
[29] Compares multiple groups at a single time point

layouts and design (e.g. filtered permeability, public realm design, stepped tracks, shared space, kerbs, sharrows); signal control (e.g. advanced stop lines, dealing with conflicts with left turning motor traffic (hold the left, cycle gating, early start), dealing with right turning cycle traffic (two-stage right turn), multiple lane approaches, markings within the junction); the design, maintenance and good practice in implementation of road signs (e.g. direction signing, advisory, warning and regulatory signs); design of roundabouts (implied roundabouts and mini-roundabouts); crossings (e.g. priority crossings of the carriageway, refuge islands, informal crossings, signal controlled crossings of carriageways)

b. **Interventions concerning the law and rules of the road.** These included Highway Code; road traffic laws (e.g. turn left on red, 'give way on turn' rule, no overtaking of cyclists on cycle streets); civil liability and insurance; speed limits (e.g. 20 mph limits, 20 mph zones); and (civil) enforcement as well as lack of enforcement.

c. **Training and testing interventions.** These included interventions that involve practical training and obtaining and maintaining driving qualifications; training for motorists (e.g. Compulsory Basic Training, driving lessons); training for cyclists and others in cycle safety (e.g. Bikeability) or for pedestrians in safe road crossing.

d. **Road user education interventions.** These included education drives via school settings, media or other settings (e.g. charities); or as part of rehabilitation schemes (e.g. diversionary courses such as national speed awareness courses or advertising and communication campaigns (e.g. Government's THINK campaign).

e. **Vehicle and equipment interventions.** These included standards for new motor vehicles and bicycles; maintenance of motor vehicles and bicycles; safety features of motor vehicles; and safety features and equipment for bicycles and cyclists.

Types of outcome measures

To be included, primary studies had to examine either risk or perceived risk as an outcome, while evidence reviews had to either report on these outcomes or have the objective of doing so. Examples of outcome constructs for risk include absolute and relative (e.g. per kilometre walked or cycled, per capita, per user, per journey or per hour) numbers of fatalities or injuries; of personal injury collisions; or of road collisions involving cyclists or pedestrians[30] or studies reporting near misses or self-reported (non-injury) collisions. We also included studies that report on severity of collisions (in terms of severity of a resulting injury); or type of collision (e.g. 'right turning', or 'automobile turns in front of vehicle'). Examples of outcome constructs for perceived risk include the perceived risk of collision, injury or death from walking or cycling and changes in the proportion of people citing risk as a barrier to walking or cycling.

[30] The number of road collisions can be police-reported (involving personal injury) or self-reported (not involving personal injury). Other potential sources of data for the outcome constructs include hospital admissions data, death registrations, coroners' reports, crime surveys and statistics on motoring offences.

We did not include or exclude evidence based on whether or not studies reported participation rates for cycling or walking. However, where studies both outcomes related to risk/perceived risk and participation, these were also reported in the REA.

Types of settings

We excluded studies of programmes or interventions outside Europe, Australasia and North America.

Other inclusion criteria

We included only papers in English. Primary studies were only includable if published in 2005 or afterwards. Evidence reviews were includable if published in 2000 or afterwards.

Inclusion and exclusion process

Studies were screened at two stages: title and abstract, and full-text. Before each stage of screening commenced, screening tools were tested and piloted by a group of reviewers to promote inter-screener reliability. A single screener reviewed documents against inclusion criteria at title and abstract stage. At full-text stage, studies identified for inclusion by the screener were double-checked by a second reviewer.

We used Rayyan systematic review screening software to help screen studies at title and abstract stage (Ouzzani et al. 2016). The software uses machine-learning algorithms to learn which studies are likely to be relevant to a review and which are not. It learns from inclusion and exclusion decisions made by the research team and prioritises more relevant papers for screening. This allowed us to prioritise the most relevant results from our search of academic databases.

Study prioritisation

Given the short time period available to the research team to complete this REA, the number of studies included for synthesis was limited to approximately 50 (51 studies were actually included). We used the following heuristics to determine which of the studies that met our criteria for inclusion at full-text should be prioritised for synthesis.

Relevance was determined using the criteria below applied in descending order (criterion a., most important through to criterion e. least important).

a. Intervention. We prioritised breadth of coverage over depth to ensure that all categories of intervention and as many intervention types as possible were covered. This meant that evidence reviews such as systematic reviews covering multiple interventions were prioritised.

b. Outcome. Studies that explore both risk (or perceived risk) and participation were prioritised.

c. Geographic setting. Studies from the UK, Netherlands, Denmark, Sweden and Finland, Germany, Austria, Switzerland and Norway were prioritised. Studies from the UK were prioritised given their applicability to a UK context. In addition, studies from the Netherlands, Denmark, Sweden, Finland, Germany, Austria, Switzerland and Norway were also prioritised, having been identified as European countries with a combination of an excellent road safety record and high rates of cycling.

d. Methodology. Evidence reviews synthesising multiple studies or primary studies with stronger experimental and quasi-experimental designs were prioritised.

e. Publication date. More recent publications were prioritised.

Data extraction

Data extraction tools were piloted before use, after which data extraction was undertaken by a single researcher with key aspects double-coded by a senior researcher.

Details on study design were extracted for all included studies as an indication of study quality. For evidence reviews, we also assessed whether a systematic search and a clear appraisal of included study quality had been conducted[31].

Our data extraction template is outlined in Appendix 5.

Synthesis

Following data extraction, we narratively synthesised the 51 prioritised studies using the 'framework method'. This involved establishing a matrix where columns represent the key thematic areas and research questions of the research, and rows represent evidence reviewed. Each article was appraised and key information summarised in the relevant cells with a link or reference back to the original source. In the case of this REA, the key thematic areas were the five categories of intervention, the intervention types and the different outcomes of interest (risk/perceived risk and participation). This method of presentation has the advantage of linking summaries explicitly to thematic areas, enabling the evidence for each research question to be easily viewed and interpreted.

[31] Studies were seen to have undertaken a systematic search if they clearly reported both resources searched and any search string(s). Studies were seen to have undertaken quality appraisal if they provided an assessment of study quality via a recognised risk of bias or quality appraisal tool such as those outlined in the in Chapter 8 of the Cochrane Handbook (http://handbook-5-1.cochrane.org/)

Appendix 2: Databases searched

Database	Date searched
Transport Database (1988 to February 2018)	19th March 2018
Scopus	21st March 2018
Web of Science (WoS)	19th March 2018
PsycInfo	21st March 2018
Education Resources Information Center (ERIC)	22nd March 2018
Medline	22nd March 2018
Epistemonikos	22nd March 2018

Appendix 3: Online repositories searched

Name	Link	Date searched
UK Department for Transport	https://www.gov.uk/government/publications?departments%5B%5D=department-for-transport	23/03/2018
Swedish National Road and Transport Research Institute	http://www.vti.se/en/	23/03/2018
Federal Ministry of Transport and Digital Infrastructure, cycle portal (Germany)	https://nationaler-radverkehrsplan.de/en/literature/research	23/03/2018
Ministry of Infrastructure and Water Management (The Netherlands)	https://www.government.nl/ministries/ministry-of-infrastructure-and-water-management	23/03/2018
Dutch Safety Board	https://www.onderzoeksraad.nl/en	23/03/2018
Cycling Embassy of Denmark	http://www.cycling-embassy.dk/category/press/publications/	23/03/2018
Cycling Embassy of Great Britain	https://www.cycling-embassy.org.uk/wiki/knowledge-base	27/03/2018
Safety Literature (SafetyLit)	https://www.safetylit.org/	04/04/2018
Transport Research International Documentation (TRID)	https://trid.trb.org/	27/03/2018
Transport for London	https://tfl.co.uk	27/03/2018
SafetyCube	https://www.roadsafety-dss.eu/#/	28/03/2018
Transport Research Laboratory (TRL)	https://trl.co.uk/	04/04/2018
Sustrans	https://www.sustrans.org.uk/policy-evidence/evidence	27/03/2018
Systematic Reviews from Collaboration for Accident Prevention and Injury Control (CAPIC)	http://www.capic.org.uk	Not searched – Website inaccessible at time of search
Road Safety Observatory	http://www.roadsafetyobservatory.com/	04/04/2018
Parliamentary Advisory Council for Transport	http://www.pacts.org.uk/news-	23/03/2018

Safety	publications/reports/	
SWOV Institute for Road Safety Research	https://www.swov.nl/en	03/04/2018
Finnish Road Safety Council	https://www.liikenneturva.fi/en/	03/04/2018
National Highway Traffic Safety Administration	https://www.nhtsa.gov/research-data	03/04/2018
Transport Scotland	https://www.transport.gov.scot/	25/03/2018
International Transport Forum	https://www.itf-oecd.org/	23/03/2018
UN Road Safety Collaboration	http://www.who.int/roadsafety/en/	23/03/2018
Australian Road Research Board	https://arrb.com.au/	23/03/2018
German Road Safety Council	www.dvr.de/dvr/kurzarstellung_en/	23/03/2018
Finnish Transport Agency	https://www.liikennevirasto.fi/web/en	23/03/2018
Finnish Crash Data Institute	http://www.oti.fi/en/oti/	23/03/2018
European Transport Safety Council	http://etsc.eu/about-us/	23/03/2018
Towards Zero Foundation (UK)	http://www.towardszerofoundation.org/about/	27/03/2018
Google (Advanced Search)	https://www.google.com/advanced_search	03/04/2018

Appendix 4: Search strategy

Below is the search strategy, as applied to the Transport Database Transport Database:

1 (bicycl* or (cycle* adj6 (road* or traffic or car or cars or lorry or lorries or HGV or "heavy goods" or truck or trucks or autos or automobile* or vehicle* or transport* or driver* or driving or motoring)) or cycling or cyclist* or bike* or pedal-power or pedestrian* or walk* or on-foot or "on foot" or non-motorised or non-motorized or "non motorised" or "non motorized" or (vulnerab* adj3 (road* or traffic))).ti,ab,hw. (30727)

2 (Pedestrians and Cyclists).cs. (9474)

3 1 and 2 (9113)

4 (accident* or crash* or fatal* or wound* or injur* or trauma* or fracture* or lacerat* or collision* or collid* or danger* or risk* or killed or KSI or death* or mortality or near-miss* or "near miss*").ti,ab,hw. (99002)

5 (Safety and Human Factors).cs. (72117)

6 4 or 5 (128545)

7 ("research synthesis" or "scoping review" or "rapid evidence assessment" or "systematic literature review" or "Systematic review" or "Meta-analy*" or Metaanaly* or "meta analy*").ti,ab,hw. (602)

8 ("quasi experiment*" or quasi-experiment* or "random* control* trial*" or "random* trial*" or RCT or (random* adj3 allocat*) or matching or "propensity score" or PSM or "regression discontinuity" or "discontinuous design" or RDD or "difference in difference*" or difference-in-difference* or "diff in diff" or DID or "case control" or cohort or "propensity weighted" or propensity-weighted or "interrupted time series" or (before adj5 after) or (pre adj5 post) or ((pretest or pre test) and (posttest or post test)) or "research synthesis" or "scoping review" or "rapid evidence assessment" or "systematic literature review" or "Systematic review" or "Meta-analy*" or Metaanaly* or "meta analy*" or "Control* evaluation" or "Control treatment" or "instrumental variable*" or heckman or IV or ((quantitative or "comparison group*" or counterfactual or "counter factual" or counter-factual or experiment*) adj3 (design or study or analysis)) or QED).ti,ab,hw. (28555)

9 ((impact and (evaluat* or assess* or analy* or estimat* or program* or intervention* or project or Projects)) or (effect* and (evaluat* or assess* or analy* or estimat* or program* or intervention* or project* or Projects)) or (random* and (trial or allocat* or intervention*)) or correlat* or association).ti,ab,hw. (134122)

10 7 or 8 or 9 (150781)

11 3 and 6 and 10 (1921)

12 limit 11 to (yr="2000 -Current" and english language)

Appendix 5: Data extraction Template

Broad category	Category	Further guidance
Descriptive information	*ID*	Paste record ID from full text screening record
	Coder	Initials of person completing data extraction
	Title	Publication title as it appears in document. Take from screening record.
	Authors	All authors. Take from screening record.
	Publication date	Take from screening record.
	Country	Country the study is set in.
Intervention	*Intervention description*	Briefly summarise intervention. Please do not paste text from publication. Cite page number(s) in bold.
	Intervention categories	Choose from: Infrastructure and road sign interventions, Interventions concerning the law and rules of the road, Training and testing interventions, Road user education interventions, Vehicle and equipment interventions Use tab entitled 'intervention types' to help you categorise.
	Population	Describe the target groups that the intervention targets: E.g. school children If no specific target population, write 'no specific target population'.
Quality appraisal: primary studies	*Study design: primary studies*	Choose either randomised Controlled Trial (RCT); Difference-in-Differences (DID); controlled before after (CBA); Instrumental Variables (IV); Regression Discontinuity Design (RDD); Propensity Score Matching (PSM); Interrupted Time Series (ITS); single group pre-test post-test; cross-sectional comparison; Other.
	Further comments on study design (primary studies)	Summarise or paste text from paper for all study designs. Elaborate on study design if other was chosen.
	Sample size	Report sample size. Overall sample size may be reported in text or analytical tables. It may be reported as total number of participants or observations. Please specify.

Quality appraisal: evidence reviews	*Study design: evidence reviews*	Choose from systematic review, rapid evidence assessment, rapid review, literature review, meta-analysis, other synthesis
	Further comments on study design (evidence reviews)	If other synthesis, describe here
	Systematic search	Do they list the resources (databases and websites) searched? Do they provide a search string for databases?
	Quality appraisal	Did the synthesis study quality appraise the studies it includes?
Outcomes of intervention	*Outcomes measured*	Drop down menu - please choose from risk, perceived risk and participation. List all that apply.
	Operationalisation of risk	How outcome is measured (list all outcome measures separately) Include page numbers citing page where outcome is defined.
	Outcome direction: risk	Direction of impact. Select increase, reduction or no change.
	Outcome size: risk	Size of impact. Report all mentions of an outcome construct in text, tables or figures. List the coefficient or effect size estimate, metric and some measure of the following (confidence intervals, p value, or statistical significance denoted by *, **, or ***. Include page number(s) for all of the following, where available: table, text, coefficient or effect size estimate.
	Operationalisation of perceived risk	How outcome is measured (list all outcome measures separately) Include page numbers citing page where outcome is defined. See tab entitled 'outcomes' for examples
	Outcome direction: perceived risk	Direction of impact. Select increase, reduction tor no change.
	Outcome size: perceived risk	Size of impact. Report all mentions of an outcome construct in text, tables or figures. List the coefficient or effect size estimate, metric and some measure of

		the following (confidence intervals, p value, or statistical significance denoted by *, **, or ***.
	Operationalisation of participation	How outcome is measured (list all outcome measures separately) See tab entitled 'outcomes' for examples
	Outcome direction: participation	Direction of impact. Select increase, reduction tor no change.
	Outcome size: participation	Size of impact. Report all mentions of an outcome construct in text, tables or figures. List the coefficient or effect size estimate, metric and some measure of the following (confidence intervals, p value, or statistical significance denoted by *, **, or ***.
	Outcome notes	Add notes on outcomes where needed.
Reviewer comments	*Reviewer comments*	Other notes by reviewer.

Appendix 6: Studies included in the review and prioritised for synthesis

Arbogast, H., Patao, M., Demeter, N., Bachman, S., Devietti, E., Upperman, J. S., and Burke, R. V. (2018) The effectiveness of installing a speed hump in reducing motor vehicle accidents involving pedestrians under the age of 21, *Journal of Transport and Heath*, 8: 30-34

Bonander, C., Nilson, F. and Andersson, R. (2014) The effect of the Swedish bicycle helmet law for children: An interrupted time series study, *Journal of Safety Research,* 51:15-22

Brook Lyndhurst (2016) *Investing in Cycling & Walking: Rapid Evidence Assessment.*

Camden, A., Buliung, R., Rothman, L., Macarthur, C. and Howard, A. (2012) The impact of pedestrian countdown signals on pedestrian-motor vehicle collisions: a quasi-experimental study, *Injury Prevention*, 18 (4): 210-215.

Carroll, J., Kinnear, N., Helman, S., Hynd, D. and Cuerden, R. (2014) *Jersey Scrutiny review: Compulsory wearing of cycle helmets*. Transport Research Laboratory.

Clarke, C. F. (2012) Evaluation of New Zealand's bicycle helmet law, *New Zealand Medical Journal*, 125 (1349): 60-69.

De Pauw, E., Daniels, S., Brijs, T., Hermans, E., and Wets, G. (2014a) An Evaluation of the Traffic Safety Effect of Fixed Speed Cameras, *Safety Science*, 62: 168-174.

De Pauw, E., Daniels, S., Brijs, T., Hermans, E., and Wets, G. (2014b) To brake or to accelerate? Safety effects of combined speed and red light cameras. *Journal of Safety Research* 50 (2014) 59–65

Dennis, J., Ramsay, T., Turgeon, A. F. and Zarychanski, R. (2013) Helmet legislation and admissions to hospital for cycling related head injuries in Canadian provinces and territories: interrupted time series analysis, *British Medical Journal,* 346: 1-10.

Digioia, J., Watkins, K.E., Xu, Yanzhi., Rodgers, M. and Guensler, R. (2017) Safety impacts of bicycle infrastructure: A critical review, *Journal of Safety Research*, 61, 105-119.

DiMaggio, C., Brady, J. and Li, G. (2015) Association of the Safe Routes to School program with school-age pedestrian and cyclist injury risk in Texas, *Injury Epidemoiology*, 2 (15): 1-8

DiMaggio, C., Chen, Q., Muennig, P.A. and Li, G. (2014) Timing and effect of a safe routes to school program on child pedestrian injury risk during school travel hours: Bayesian changepoint and difference-in-differences analysis, *Injury Epidemiology*, 1 (17): 1-8.

Ducheyne, F., De Bourdeaudhuik., Lenoir, M. and Cardon, G. (2014) Effects of a cycle training course on children's cycling skills and levels of cycling to school, *Accident Analysis and Prevention,* 67: 49-60.

Fayish, A. and Gross, F. (2010) Safety Effectiveness of Leading Pedestrian Intervals Evaluated by a Before–After Study with Comparison Groups, *Journal of the Transportation Research Board*, 2198: 15-22.

Fitzpatrick, K., Chrysler S. T., Van Houten, R., Hunter W.W. and Turner, S. (2011) *Evaluation of Pedestrian and Bicycle Engineering Countermeasures: Rectangular Rapid-Flashing Beacons, HAWKs, Sharrows, Crosswalk Markings, and the Development of an Evaluation Methods Report.* Federal Highway Administration

Gamble, T., Walker, I. and Laketa, A. (2015) Bicycling campaigns promoting health versus campaigns promoting safety: A randomized controlled online study of 'dangerization', *Journal of Transport and Health,* 2 (3): 369-378.

Hodgson, C. and Worth, J. (2015) *Research into the Impact of Bikeability Training on Children's Ability to Perceive and Appropriately Respond to Hazards When Cycling on the Road.* Slough: NFER

Hynd, D., Cuerden, R., Reid, S. and Adams, S. (2009) *The potential for cycle helmets to prevent injury - a review of the evidence base.* Transport Research Laboratory.

Karkhaneh, M., Rowe, B. H., Saunders, L. D., Voaklander, D. C. and Hagel, B. E. (2013) Trends in head injuries associated with mandatory bicycle helmet legislation targeting children and adolescents, *Accident Analysis and Prevention,* 59: 206-212.

Kennedy, J. and Sexton, B. (2009) *Literature review of road safety at traffic signals and signalised crossings.* Transport Research Laboratory.

Kwan, I. and Mapstone, J. (2006) Interventions for increasing pedestrian and cyclist visibility for the prevention of death and injuries, *Cochrane Database of Systematic Review*, 4: 1-53.

Lahrmann, H., Madsen, T. K. O., Olesen, A. V., Madsen, J. C. O. and Hels, T. (2017) The effect of a yellow bicycle jacket on cyclist accidents, *Safety Science*, In Press.

Lee, R. S., Hagel, B. E., Karkhaneh, M. and Rowe, B. H. (2009) A systematic review of correct bicycle helmet use: how varying definitions and study quality influence the results, *Injury Prevention*, 15: 125-131.

Macpherson, A., Spinks, A., Cochrane review: Bicycle helmet legislation for the uptake of helmet use and prevention of head injuries. *Evidence-Based Child Health: A Cochrane Review Journal* 3.1 (2008): 16-32.

Mader, E.M. and Zick C. D. (2014) Active transportation: Do current traffic safety policies protect non-motorists? *Accident Analysis and Prevention*, 67: 7-13.

Madsen, J., Andersen, T. and Lahrmann, H. (2013) Safety effects of permanent running lights for bicycles: A controlled experiment, *Accident Analysis and Prevention*, 50: 820-829.

Mulvaney, C. A., Smith, S., Watson, M. C., Parkin, J., Coupland, C., Miller, P., Kendrick, D. and McClintock, H. (2015) Cycling infrastructure for reducing cycling injuries in cyclists, *Cochrane Database of Systematic Reviews,* 12: 1-117.

Ohlin, M., Strandroth, J. and Tingvall, C. (2017) The Combined Effect of Vehicle Frontal Design, Speed Reduction, Autonomous Emergency Braking and Helmet Use in Reducing Real Life Bicycle Injuries, *Safety Science,* 92: 338-344.

Olivier, J. and Creighton, P. (2017) Bicycle injuries and helmet use: a systematic review and meta-analysis, *International Journal of Epidemiology,* 46 (1): 278-292.

Orenstein M.R., Gutierrez, N., Rice, T. M., Cooper J. F. and Ragland D.R. (2007) *Safe Routes to School: Safety & Mobility Analysis: Report to the California Legislature.* University of California Berkely Transporation Library.

Porchia, B. R., Baldasseroni, A., Dellisanti, C., Lorini, C. and Bonaccorsi, G. (2014) Effectiveness of two interventions in preventing traffic accidents: a systematic review, *Ann Ig,* 26 (1): 63-75.

Porter, B., Neto, I., Balk, I and Jenkins, J. (2016) Investigating the effects of rectangular rapid flash beacons on pedestrian behavior and driver yielding on 25 mph streets: a quasi-experimental field study on a university campus, *Transportation Research Part F: Traffic Psychology and Behaviour*, 42 (3): 509-521.

Prati, G. (2018) The effect of an Italian nationwide mandatory visibility aids law for cyclists, *Journal of Transport and Health,* In press.

Reed, S. (2017) *Cyclist Protective Clothing*. European Road Safety Decision Support System, developed by the H2020 project SafetyCube. Available at: www.roadsafety-dss.eu

Reid, S. and Adams, S. (2011) *Infrastructure and Cyclist Safety.* Transport Research Laboratory.

Retting, R., Ferguson, S. and McCartt, A. (2003) A Review of Evidence-Based Traffic Engineering Measures Designed to Reduce Pedestrian–Motor Vehicle Crashes, *American Journal of Public Health*, 93 (9): 1456-1463.

Reynolds, C. C., Harris, M. A., Teschke, K., Cripton, P. A. and Winters, M. (2010) The impact of transportation infrastructure on bicycling injuries and crashes: a review of the literature, *Environmental Health,* 8 (47): 1-19.

Richmond S. A., Zhang Yu., Stover, A., Howard, A. and Macarthur, C. (2014) Prevention of bicycle-related injuries in children and youth: a systematic review of bicycle skills training interventions, *Injury Prevention,* 20: 191-195.

Rothman, L., Macpherson, A., Buliung, R., Macarthur, C., To, T., Larsen, K. and Howard, A. (2015) Installation of speed humps and pedestrian-motor vehicle collisions in Toronto, Canada: a quasi-experimental study, *BMC Public Health*, 15 (774): 1-7.

Rothman, L., Perry, D., Buliung, R., Macarthur, C., To, T., Macpherson, A., Larsen, K. and Howard, A. (2015) Do school crossing guards make crossing roads safer? A quasi-experimental study of pedestrian-motor vehicle collisions in Toronto, Canada, *BMC Public Health,* 15: 732.

Saade, J. (2017) *Autonomous Emergency Braking AEB (pedestrians & cyclists),* European Road Safety Decision Support System, developed by the H2020 project SafetyCube. Available at: www.roadsafety-dss.eu.

Schwebel, D C., Barton, B.K., Shen, J., Wells, H.L., Bogar, A., Heath, G. and McCullough, D. (2014) Systematic review and meta-analysis of behavioral interventions to improve child pedestrian safety, *Journal of Pediatric Psychology*, 39 (8): 826-845.

Silla, A., Leden, L., Rama, P., Scholliers, J., Van Noort, M. and Bell, D. (2017) Can cyclist safety be improved with intelligent transport systems? *Accident Analysis and Prevention*, 105: 134-145.

Soteropoulos, A and Stadlbauer, S. (2017) *Convert junction to roundabout,* European Road Safety Decision Support System, developed by the H2020 project SafetyCube. Available at: www.roadsafety-dss.eu.

Thomas, B., & DeRobertis, M. (2013). The safety of urban cycle tracks: A review of the literature. *Accident Analysis & Prevention*, *52*, 219-227.

TNS (2015) *THINK! Cycling 'Safety Tips' campaign evaluation 2015*

Turner, C., McClure, R., Nixon, J. and Spinks, A. (2004) Community-based programmes to prevent pedestrian injuries in children 0-14 years: a systematic review, *Injury control and Safety Promotion*, 11 (4): 231-237.

Usami, D.S. and Ammari, A. (2017) *Cycle lane treatments; cycle path treatments,* European Road Safety Decision Support System, developed by the H2020 project SafetyCube. Available at: www.roadsafety-dss.eu.

Walter S.R., Olivier, J., Churches, T. and Grzebieta, R. (2011) The impact of compulsory cycle helmet legislation on cyclist head injuries in New South Wales, Australia, *Accident Analysis and Prevention*, 43 (6): 2064-2071.

Wesson, D. E., Stephens, D., Lam, K., Parsons, D., Spence, L. and Parkin, P. C. (2008) Trends in pediatric and adult bicycling deaths before and after passage of a bicycle helmet law, *American Academy of Pediatrics*, 122 (3): 605-610.

Zegeer ,C., Blomberg R., Henderson, D., Masten S., Marchetti, L., Levy M., Fan, Yi., Sandt, L., Brown, A., Stutts, J. and Thomas L.. (2008) Evaluation of Miami-Dade Pedestrian Safety Demonstration Project, *Transportation Research Record*, 2073: 1-10.

Appendix 7: Descriptive tables for included articles

**** Significant at 99% confidence level, ** significant at 95% confidence level, * significant at 90% confidence level.*

7.1– Infrastructure and road sign interventions				
Author and Year	Country	Study design	Intervention description	Outcomes summary
Arbogast et al. 2018	United States	Single group pre-test post-test	Installation of speed hump Target group: school children	Reduced risk (injuries and fatalities) - Statistical significance not reported
Brook Lyndhurst 2016	Multi-country	Rapid evidence assessment (n=55)	Segregated cycle tracks, coloured bicycle lanes, cycle tracks and bicycle phases in traffic signals and advanced stop lines	Segregated cycle tracks lead to a lower risk of cyclist injury as well as accidents. Coloured bicycle lanes and bicycle phases in traffic signals appear to be effective in reducing collisions. Advance stop lines do not reduce cyclist safety, but increase cyclists' perception of safety.
Camden et al. 2012	Canada	Single group pre-test post-test Sample: 9,262 collisions	Installation of pedestrian countdown signals	Risk (Total collisions) – No statistically significant effect Risk (No injury Risk Ratio) - No statistically significant effect Risk (Minor injury RR) - No statistically significant effect Risk (Major injury RR) - No statistically significant effect Risk (Fatal injury RR) - No statistically significant effect

De Pauw et al. 2014a	Belgium	Controlled Before-After (CBA)	Installation of speed cameras	Reduced risk (cyclist injury) Statistical significance not reported Reduced risk (pedestrian injury) Statistical significance not reported
De Pauw et al. 2014b	Belgium	Controlled Before-After (CBA)	Installation of speed and red light cameras	Reduced risk (cyclist injury) Statistical significance not reported Risk (pedestrian injury) No effect
DiGioia et al. 2017	United States	Literature review (n=19)	Cycle lanes, cycle tracks, street lighting etc.	Risk (conflict rate) – Inconclusive Risk (collision rate) – Inconclusive Risk (collision severity) – Inconclusive Risk (injury collision rate) – Inconclusive
Di Maggio et al. 2014	United States	Difference-in-Differences (DID)	Introduction of Safe Routes To School program. This included traffic calming measures, improvements to sidewalks, pedestrian/ bicycle access and education on safety	Reduced risk (number of pedestrian collisions involving children) – not statistically significant
Di Maggio et al. 2015.	United States	Difference-in-Differences (DID)	Safe Routes to School program (see description in Di Maggio et al. 2015).	Reduced risk (annual rates of injury risk for pedestrian and cyclist school-age children) ** Reduced risk (annual rates of injury risk for pedestrian and cyclist adults aged 30-64) ** Reduced risk (pedestrian and cyclist injury incidence rate ratio for school-age children) ** Reduced risk (pedestrian and cyclist risk of fatality for school-age children) – not statistically significant
Fayish and Gross 2010	United States	Comparison at single time between treatment and comparison group	Intersections with leading pedestrian interval (LPI)	58.7% reduction** in risk (pedestrian-vehicle collisions)

Fitzpatrick et al. 2011	United States	Literature review (n= not reported)	The High intensity Activated crossWalK (HAWK); (3) Shared lane markings	The researchers find that HAWK led to a reduction in total collisions (any type of collision) and pedestrian collisions. Findings for shared lane markings were inconclusive.
Kennedy and Sexton 2009	Multi-country	Literature review (n = not reported) Systematic search	Traffic signals and signalised crossings	The authors note the limited evidence base, but tentatively conclude that signalised crossings reduce pedestrian collisions. Limited evidence that signal-controlled roundabouts are safer than normal roundabouts, especially for cyclists. Puffin and pelican crossings have a similar safety record (in terms of frequency of pedestrian collisions) and left turn on red increases pedestrian and cycle collisions.
Mulvaney et al. 2016	Multi-country	Systematic review and meta-analysis (n=21) Systematic search and quality appraisal	Cycle lanes, cycle routes and networks	Risk (ratio of cycle collisions) for cycle lanes – No statistically significant effect Risk (ratio of cycle collisions) for cycle routes and networks - No statistically significant effect
Orenstein et al. 2007	United States	Controlled Before-After (CBA) Sample: 350 schools	Introduction of Safe Routes To School programme. This included traffic calming measures, improvements to sidewalks, pedestrian/ bicycle access and education on safety – for 5-17 year olds.	Risk (collision rates of cyclists and pedestrians) – No statistically significant effect However, participation rates for walking and cycling may have decreased in control areas and increased in treatment areas and when this is accounted for, the programme does reduce collision rates – Statistical significance not reported
Porchia et al. 2014	Italy	Systematic review (n=4)	Introduction of measures to improve cyclist and pedestrian visibility	Authors find that street lighting can prevent road traffic collisions, injuries and fatalities, can increase pedestrian night-time visibility reduce night-time pedestrian collisions, and the risk of night time pedestrian collisions was reduced with cyclist visibility interventions.

Porter et al. 2016	United States	Single group pre-test post-test Sample: 256 students	Introduction of rectangular rapid flash beacons on college campus. Target group: US college age students	Reduced self-reported perceived risk (feelings of safety when crossing streets around the University) nearly two months after installation of RRFBs Self-reported perceived risk (being in a near-miss as a pedestrian or being in a near miss as a driver) – No statistically significant effect
Reid and Adams 2011	United Kingdom	Literature review (n=33)	Cycle lanes, tracks, junctions and traffic calming measures	The authors find: -Little evidence that marked cycle lanes provide benefit on risk for cyclists, but segregated tracks may reduce risk or severity of collisions. -Raised cycle track crossings, cycle lanes continued across junctions and signalisation of large roundabouts can reduce rates of cyclist casualties. -Traffic calming measures such as chicanes, pedestrian refuge islands and placemaking can reduce speeds, casualties for all road users and even increase rates of levels of cycling. -Cycle Advanced Stop Lines show little benefit on measures of risk for cyclists.
Retting et al. 2003	North America	Literature review (n = not reported)	Engineering solutions for speed control, separation of pedestrians from vehicles, and measures that increase visibility and conspicuity of pedestrians	-Single-lane roundabouts, pavements and pedestrian refuge islands reduce the risk of pedestrian-motor vehicle collision. - The following 'show promise' based on a limited evidence base: advance stop lines, in pavement flashing lights, automatic pedestrian detection at walk signals and exclusive pedestrian signal phasing which stops all vehicle traffic for part or all of the pedestrian crossing signal -Street lighting can reduce risk of pedestrian motor vehicle collision

Reynolds et al. 2009	Multi-country	Literature review (n=23) Systematic search	transportation infrastructure (roundabouts, traffic lights, bike lanes or tracks)	Authors note that evidence is sparse. However, based on the evidence reviewed, they note that purpose-built bicycle only facilities reduce the risk of collisions and injuries compared to cycling on-road with traffic or off-road with pedestrians. Street lighting, paved surfaces, and low-angled grades also appear to improve cyclist safety.
Rothman et al. 2015a	Canada	Single group pre-test post-test	speed hump installation	Reduced** risk (incidence rate of pedestrian-motor vehicle collisions) Risk reduced more for children than for adults
Rothman et al. 2015b	Canada	Single group pre-test post-test Sample: 568 school crossing guards	Implementation of school crossing guards (school crossing patrol officers)	Risk (pedestrian-motor vehicle collisions) - No statistically significant effect
Soteropoulos and Stadtlbauer 2017	Multi-country	Literature review (n=18) Systematic search	conversion of junctions to roundabouts	Roundabouts with cycle lanes increase risk (bicycle collisions), whereas roundabouts with cycle tracks reduce risk (bicycle collisions)
Thomas and DeRobertis 2013	Multi-country	Literature review (n=23)	Cycle tracks with physical barriers, intersection features, e.g. speed bumps, dedicated cyclists signals	Authors explore the effect of cycle tracks that separate cyclists from the motorised vehicle traffic by a physical barrier. They find that certain intersection features can lead to reduced collisions and injuries: Bringing cycle tracks closer to vehicle traffic at intersection approach; Raising vehicle crossings (like a speed bump) at cycle lane intersections; Using advance stop lines for motor vehicles (at least 20m before the intersection); Dedicated cyclist signals to separate cyclists from turning vehicles. They also conclude that one-way cycle tracks are safer than two-way tracks (frequency of cyclist collisions).

Usami and Amarri 2017	Multi-country	Literature review (n=3) Systematic search	Cycle lanes (visually protected space for bicycle traffic) and cycle tracks (physically protected space for bicycle traffic)	Installation of non-separated cycle lanes leads to a small though non-statistically significant reduction in bicycle accidents. Furthermore, they find that physically separated cycle tracks can result in an increase in bicycle accidents, particularly at intersections.

7.2 – Interventions concerning law and rules of the road				
Author and Year	Country	Study Design	Intervention	Outcomes
Bonander and Andersson, 2014	Sweden	Interrupted Time Series (ITS) Sample: 56,477 cyclist hospital admissions	Swedish bicycle helmet law for children under the age of 15	Reduced risk (head injury for male children aged below 15) ** No significant effect for female children under 15 years old
Brook Lyndhurst 2016	United Kingdom	Rapid evidence assessment (n = 55)	Speed limits Legislation requiring routes to school to be made safe	Authors find evidence that -speed restrictions such as 20 mph can reduce numbers of cyclist casualties and increase participation -safe routes to school can reduce child casualty rates
Carroll et al. 2014	United Kingdom	Literature review (n = 65) Systematic search	Effects of mandatory bike helmet legislation	Authors conclude that mandatory bike helmet legislation is likely to reduce head related trauma and there is no evidence of an increase in injuries. The review does not come to a definitive conclusion regarding impact on participation – if there is an effect – it is of a short-term reduction in child cycling participation.
Clarke 2012	New Zealand	Literature review (n = 7)	Evaluation of the 1994 New Zealand Helmet Law	Authors conclude that the legislation led to a reduction in bicycle usage and in increase in cyclist injury risk.
Dennis et al. 2013	Canada	Interrupted Time Series (ITS) Sample: 66,716 observations	Mandatory helmet legislation aimed at under 18s	The study did not detect an effect for legislation on the rate of hospital admissions for cycling related head injuries.

Karkhaneh et al. 2013	Canada	Single group pre-test post-test	Mandatory Helmet legislation Target group: schoolchildren	Reduced risk (bicycle related head injuries in children) ** Reduced risk (cyclist non-head injuries in adolescents) ** Reduced risk (cyclist non-head injuries in adults) **
Macpherson and Spinks 2008	Multi-country	Systematic review (n = 6) Systematic search and quality appraisal	Mandatory Helmet legislation	The authors conclude that helmet legislation appears to be effective in increasing helmet use and decreasing head injury rates. However they note that few high quality studies report on these outcomes.
Mader and Zick 2014	United States	Regression analysis Sample: 50 states, 550 observations	State expenditures for highway law enforcement	Reduced risk (non-motorist fatalities) **
Mulvaney et al. 2016	Multi-country	Systematic review and meta-analysis (n=21) Systematic search and quality appraisal	Reduced speed limit to 20km/h in urban areas	Based on narrative synthesis of a small number of studies, authors find that 20mph speed restrictions in urban areas may reduce cyclist collisions.
Ohlin et al. 2017	Sweden	Cross-sectional Comparison Sample: 1,184 pedestrians and 2,029 cyclists	Reduced speed limit to 40km/h	The study finds that speed limit reductions to 40kmh (approx. 25 mph) reduce the injury risk for pedestrians and cyclists, though only effects for a small number of types of injury severity categories for cyclists are statistically significant.
Olivier and Creighton 2017	Australia	Systematic review, Meta-analysis (n = 40) Systematic	Bicycle helmet legislation	The authors note the finding by Macpherson and Spinks (2008) that helmet legislation is beneficial, but that later studies have found mixed results, with some indicating legislation is effective, has no effect or produces mixed effects by gender.

		search		
Prati 2018	Italy	Interrupted Time Series (ITS) Sample: 231,962 observations	Introduction of mandatory visibility aids law in Italy	Reduced risk (number of bicycles involved in road collision) not statistically significant
Reid. and Adams 2011	United Kingdom	Literature review (n = 33)	Regulation of motor vehicle speeds and traffic calming	The authors conclude that speed restrictions of 20mph can result in reduced numbers of casualties for all road users and a reduction in severity of casualties for cyclists. For traffic calming measures such as chicanes and pedestrian crossing refuges, there is evidence that they can reduce speeds, reduce casualties for all road users and even increase levels of cycling.
Walter et al. 2011	Australia	Interrupted Time Series (ITS) Sample: 2,154 observations	Legislation making helmets mandatory for cyclists	Reduced risk (head injury admissions cyclists) ***
Wesson et al. 2008	United States	Interrupted Time Series (ITS)	The introduction of mandatory helmet legislation for children aged 18 and younger	Reduced risk (bicycle-related mortality rates children aged 1-15 years) ** No significant effect (bicycle-related mortality rates children aged 16 years and above)

7.3 – Training and testing interventions				
Author and year	Country	Study design	Intervention	Outcomes summary[1]
Ducheyne et al 2014	Belgium	Randomised Controlled Trial (RCT) Sample: 3 schools, 135 children	Schools based cycling training programme for Primary school children aged 9-10	No significant effect on children's cycling to school was found (minutes/week) No significant effect on parental perceived risk of their children cycling was found
Hodgson and Worth 2015	United Kingdom	Multilevel regression	Introduction of Bike-ability: a training programme to get	Risk (position on the road) decrease** Perceived Risk (hazard perception and

		modelling Sample: 29 schools, 668 pupils	more people cycling, more safely, more often Target group: children aged 9-10	appropriate response ability) decrease **
Richmond et al. 2014	Multi-country	Systematic Review (n=25) Systematic search and quality appraisal	Bicycle skills training programmes to prevent injuries in children and youth aged under 19	Authors identify an effect on cycling safety knowledge but no statistically significant change in risk (injury frequency and severity, safe cycling behaviour and attitudes) following training programmes in included studies.
Schwebel et al. 2014	Multi-country	Systematic Review; meta-analysis (Papers n=19, Studies n = 25) Systematic search and quality appraisal	Behavioural interventions to teach children aged 3-11 road safety: small-group training, classroom training, computer-based or virtual reality training, board games, peer-group activities, and videos.	Safety (pedestrian safety behaviours) increase** One-to-one or small-group training strategies found to be effective. Other intervention types produced mixed results.
Turner et al. 2004	Multi-country	Systematic Review (n=4) Systematic search	Community-based interventions for children under 14 years (injury prevention programmes adopting more than a single strategy and targeted a whole community or group of individuals.)	Authors note the small evidence base, but tentatively conclude that community-based interventions can be effective in reducing pedestrian injury rates and that more complex programmes are likely to be more effective.

7.4 – Road user education				
Author and year	Country	Study design	Intervention description	Outcomes summary (outcome type, direction of effect, size of effect)[1]

Gamble et al. 2015	United Kingdom	Randomised Controlled Trial (RCT) Sample: 228 participants	Online education campaign to promote health and safety literature for cycling behaviour Target group: adults	Perceived risk (online survey instrument) no change – no statistically significant effect Participation (online survey instrument) no change – no statistically significant effect
Lee et al. 2009	Multi-country	Systematic Review (n=11) Systematic search and quality appraisal	Correct bicycle helmet use	Only a single included study reports the impact of helmet fit on the risk of head injury on children, reporting a significant reduction in head injuries for those wearing excellent fitting helmets compared those with a poor fit. School-based educational programmes appear to be effective in promoting correct helmet use among schoolchildren.
TNS BRMB 2015	United Kingdom	Single group pre-test, post-test	The Think! poster campaign providing road safety tips to cyclists and motorists	The authors report an increase in claimed safe cycling behaviours but no effect for motorists.
Zegeer et al. 2008	United States	Interrupted Time Series (ITS) Sample: 17,308 observations	Pedestrian education campaign via workshops, leaflets, videos, training police officers in pedestrian safety and enforcement, and investment on infrastructure such as pedestrian warning signs or traffic islands	Risk (pedestrian collisions) reduction*

[1] *** *Significant at 99% confidence level, ** significant at 95% confidence level, * significant at 90% confidence level.*

7.5 – Vehicle and equipment interventions				
Author and year	Setting	Study design	Intervention	Outcomes summary[1]
Brook Lyndhurst 2016	Multi-country	Rapid evidence assessment (n=55)	Cycle hire / bikeshare	The authors find some evidence from econometric models that bikeshare schemes can reduce injury and mortality rates compared to normal bicycles. They also find that bikeshare schemes can increase the number of bicycle trips.

Carroll et al. 2014	Multi-country	Literature review (n not reported) Systematic search	Helmet use	The review finds that helmet wearers involved in collisions suffer fewer injuries than unhelmeted cyclists.
Hynd et al. 2009	Multi-country	Literature review (n=20) Systematic search	Bicycle helmet use	Most hospital admissions studies (typically case-control) find that helmets are effective in reducing head injuries, whereas population-based studies (typically longitudinal) show little to no effect. Authors note the methodological limitations of the evidence base.
Kwan and Mapstone 2006	Multi-country	Systematic review (n=42) Systematic search and quality appraisal	Visibility aids for the protection of pedestrians and cyclists	The review found no randomised controlled trials or controlled before and-after studies which explore the effect of visibility on the occurrence of pedestrian and cyclist-motor vehicle collision.
Lahrmann et al. 2017	Denmark	Randomised Controlled Trial (RCT) Sample: 6,793 participants	Yellow high visibility jacket for cyclists	Risk (self-reported multiparty accident rate ratio for personal injury accidents involving cyclists) reduction**
Lee et al. 2009	Multi-country	Systematic review (n=11) Systematic search and quality appraisal	Correct bicycle helmet use Target group: schoolchildren	Only a single included study reports the impact of helmet fit on the risk of head injury on children, reporting a significant reduction in head injuries for those wearing excellent fitting helmets compared those with a poor fit. School-based educational programmes appear to be effective in promoting correct helmet use among schoolchildren.
Madsen et al. 2013	Denmark	Randomised Controlled Trial (RCT) Sample: 3,845 participants	Permanent running lights mounted to bicycles	Risk (solo and multiparty accidents) reduction** Risk (multiparty accidents with personal injury) reduction**
Ohlin et al. 2017	Sweden	Cross-sectional comparison Sample: 1,184 pedestrians and	Vehicle frontal design, speed reduction, autonomous emergency braking	Risk of permanent medical impairment of pedestrians: reduction*** Risk of permanent medical

		2,029 cyclists	and helmet use	impairment of cyclists: reduction** Injury severity for pedestrians (measured in Maximum Abbreviated Injury Scale (MAIS)): reduction* Injury severity for cyclists (measured in Maximum Abbreviated Injury Scale (MAIS)): reduction – not statistically significant *Cyclist head injuries:* Injury Severity (measured in Abbreviated Injury Scale (AIS) [32]: reduction*** Risk of permanent medical impairment of the head: reduction** *Lower extremities and pelvis injuries (cyclists):* Injury Severity (measured in AIS) not statistically significant Risk of permanent medical impairment to lower extremities (cyclists): reduction** *Other injuries (cyclists):* Risk of permanent medical impairment: reduction*** Injury Severity (measured in AIS) : reduction***
Olivier and Creighton 2017	Multi-country	Systematic review, Meta-analysis (included n=43; meta-analysis n=40) Systematic search	Bicycle helmet use	Risk (head injury) reduction** Risk (serious head injury) reduction** Risk (facial injury) reduction** Risk (fatal head injury) reduction**

[32] Abbreviated Injury Scale (AIS) is a scale used for measuring injury severity. AIS is a widely used severity scoring system that classifies injuries by body region according to its relative importance on a 1–6 point ordinal scale, where 1 = minimum and 6 = maximum (Ohlin et al. 2017, p. 339).

Reed 2017	Multi-country	Literature review (n=5) Systematic search	Cyclist protective clothing – high-visibility clothing	The authors find that high visibility clothing reduces the risk of collisions and time spent off work due to injuries sustained through collisions
Saadé 2017	Multi-country	Literature review (n=6) Systematic search	Introduction of Autonomous Emergency Braking (AEB) for motorised vehicles	The authors report that AEB reduces the number and severity of pedestrian and cyclist accidents.
Silla et al. 2017	Finland	Regression modelling	Intelligent transport systems	The authors found that intelligent transport systems can reduced risk (cyclist fatalities and injuries)

Appendix 8: Studies eligible for inclusion but not prioritised for synthesis

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