Speed cameras for the prevention of road traffic injuries and deaths (Review)

Wilson C, Willis C, Hendrikz JK, Le Brocque R, Bellamy N

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[Intervention Review]

Speed cameras for the prevention of road traffic injuries and deaths

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ABSTRACT

Background

It is estimated that by 2020, road traffic crashes will have moved from ninth to third in the world ranking of burden of disease, as measured in disability adjusted life years. The prevention of road traffic injuries is of global public health importance. Measures aimed at reducing traffic speed are considered essential to preventing road injuries; the use of speed cameras is one such measure.

Objectives

To assess whether the use of speed cameras reduces the incidence of speeding, road traffic crashes, injuries and deaths.

Search strategy

We searched the following electronic databases covering all available years up to March 2010; the Cochrane Library, MEDLINE (WebSPIRS), EMBASE (WebSPIRS), TRANSPORT, IRRD (International Road Research Documentation), TRANSDOC (European Conference of Ministers of Transport databases), Web of Science (Science and Social Science Citation Index), PsycINFO, CINAHL, EconLit, WHO database, Sociological Abstracts, Dissertation Abstracts, Index to Theses.

Selection criteria

Randomised controlled trials, interrupted time series and controlled before-after studies that assessed the impact of speed cameras on speeding, road crashes, crashes causing injury and fatalities were eligible for inclusion.

Data collection and analysis

We independently screened studies for inclusion, extracted data, assessed methodological quality, reported study authors' outcomes and where possible, calculated standardised results based on the information available in each study. Due to considerable heterogeneity between and within included studies, a meta-analysis was not appropriate.

Main results

Thirty five studies met the inclusion criteria. Compared with controls, the relative reduction in average speed ranged from 1% to 15% and the reduction in proportion of vehicles speeding ranged from 14% to 65%. In the vicinity of camera sites, the pre/post reductions ranged from 8% to 49% for all crashes and 11% to 44% for fatal and serious injury crashes. Compared with controls, the relative improvement in pre/post injury crash proportions ranged from 8% to 50%.

Authors' conclusions

Despite the methodological limitations and the variability in degree of signal to noise effect, the consistency of reported reductions in speed and crash outcomes across all studies show that speed cameras are a worthwhile intervention for reducing the number of road traffic injuries and deaths. However, whilst the the evidence base clearly demonstrates a positive direction in the effect, an overall magnitude of this effect is currently not deducible due to heterogeneity and lack of methodological rigour. More studies of a scientifically rigorous and homogenous nature are necessary, to provide the answer to the magnitude of effect.

PLAIN LANGUAGE SUMMARY

Do speed cameras reduce road traffic crashes, injuries and deaths?

Road traffic crashes are a major cause of death and disability. The speed at which a vehicle travels is an important determinant of injury; the faster the vehicle is travelling, the greater the energy inflicted on the occupants during a crash, and the greater the injury.

Excessive speed (driving faster than the posted limit or too fast for the prevailing conditions) has been found to contribute to a substantial number of crashes. It is predicted that, if the number of speeding drivers is reduced, both the likelihood and severity of a crash will be lowered. Therefore, interventions aimed at reducing traffic speed are considered essential to preventing road injuries and deaths. The enforcement of safe speeds with speed cameras and associated automated devices is one such measure.

To evaluate the effectiveness of speed cameras, the authors examined all eligible studies, that is, studies that met pre-set standard criteria. We analysed the effect of speed cameras on speeding, road traffic crashes, injuries and deaths by comparing what was happening in road areas before the introduction of speed cameras and after their introduction, and also by analysing what was happening in comparable road areas where no speed cameras were introduced during the study period.

The authors accepted a total of 35 studies for review which met the pre-set criteria. All studies reporting speed outcomes reported a reduction in average speeds post intervention with speed cameras. Speed was also reported as either reductions in the percentage of speeding vehicles (drivers), as percentage speeding reductions over various speed limits, or as reductions in percentages of top end speeders. A reduction in the proportion of speeding vehicles (drivers) over the accepted posted speed limit, ranged from 8% to 70% with most countries reporting reductions in the 10 to 35% range.

Twenty eight studies measured the effect on crashes. All 28 studies found a lower number of crashes in the speed camera areas after implementation of the program. In the vicinity of camera sites, the reductions ranged from 8% to 49% for all crashes, with reductions for most studies in the 14% to 25% range. For injury crashes the decrease ranged between 8% to 50% and for crashes resulting in fatalities or serious injuries the reductions were in the range of 11% to 44%. Effects over wider areas showed reductions for all crashes ranging from 9% to 35%, with most studies reporting reductions in the 11% to to 27% range. For crashes resulting in death or serious injury reductions ranged from 17% to 58%, with most studies reporting this result in the 30% to 40% reduction range. The studies of longer duration showed that these positive trends were either maintained or improved with time.

The quality of the included studies in this review was judged as being of overall moderate quality at best, however, the consistency of reported positive reductions in speed and crash results across all studies show that speed cameras are a worthwhile intervention for reducing the number of road traffic injuries and deaths. To affirm this finding, higher quality studies, using well designed controlled trials where possible, and studies conducted over adequate length of time (including lengthy follow-up periods) with sufficient data collection points, both before and after the implementation of speed cameras, are needed. As none of the studies were conducted in low-income countries, research in such settings is also required. There is a greater need for consistency in methods, such as international standards for the collection and reporting of speed and crash data and agreed methods for controlling bias in studies. This would allow more reliable study comparisons across countries, and therefore greater ability to provide stronger scientific evidence for the beneficial effects of speed cameras.

SUMMARY OF FINDINGS FOR THE MAIN COMPARISON [*Explanation*]

Study ID	Main outcomes (Reported by Study Authors)	RSR (95% CI) (Review Authors)	PSRRR (95% CI) (Review Authors)	Results based on	Quality of the evidence (GRADE)
	asteric* denotes studies reporting both speed and crash outcomes	*Relative speed ratio (RSR)*	*% Speeding relative rates ratio (PSRRR)*		
AU NSW 1	About 70% reduction in speeding vehicles when police present. A time halo effect lasted at least 2 days	Not reported.	0.78 (CI incalculable)	3 post occasions. 2 times of day. Speed limit (SL) = 60km/hr % vehicles speeding.	Low
*AU NSW 2	Overall mean speed reduction of about 2-3km/h seen at both experimental and control sites. Distance halo of up to 14km downstream was seen. Time halo for at least the day after enforcement	0.99 (CI incalculable)	Not reported.	10 experimental sites. 5 control sites. Cars and trucks. 2 speed limits. 2 occasions during intervention. Unweighted means of two interventions.	High
*AU NSW 3	Main findings= 5.8km/h reduction in mean speeds at 24 months at camera sites. For percentage exceeding speed limit, a 70% reduction at camera sites and a 20.9% reduction downstream at 12 months. These reductions were maintained at 24 months. For percentage exceeding speed limit by $\geq$10km/h significant reductions of 86% and 88% at 12 and 24 months respectively along camera lengths. For all speed measures upstream	Experimental sites-only pre-post differences reported. No control data reported	Experimental sites-only pre-post differences reported. No control data reported	28 experimental sites. 20 sites used for speed and % speeding. 33 matched controls. Rural, Urban and freeway roads. Data pre and at 12 and 24 months post camera	Low

	segments showed speed increases at 24 months				
*AU QLD 2	Reduction in speed and narrowing of speed distribution for 60km/h, 70km/h and 100km/h zones at experimental sites. No further information given	Graphs only.	Graphs only.	3 SLs (60, 70 and 100km/hr)	High
AU South Australia	Sharp reduction of 5 km/h in median speed on experimental roads after program launch. No further reduction observed despite intensified enforcement. However reduction sustained throughout the 15 month trial period	Graphs only.	Graphs only.	3 interventions, so results based on pre and post last intervention	Moderate
*AU Tasmania	Significant average 3.6 km/h decrease in mean speed compared to before. No time halo effect seen	0.96 (0.88 to 1.05)	Not reported.	Means of mean speeds recorded on different days within the pre and post periods Pooled variance of 3 post-period means Formula for variance of ratios.	Moderate
*AU Vic 2	Net 3.4% speed reduction after consideration of changes in average speeds that occurred at control site during the same before-after periods. The proportion of drivers exceeding the 80km/h posted speed limit decreased by a net 66%. For speeders over 90km/h, a net 79% reduction, and for those over 110km/h, a net 76% re-	Not reported	Not reported	Reported results are estimated net effects after adjusting for control and other factors	High

	duction was reported				
*CA British Columbia	A reduction from 66% to 35% in the percentage of speeding drivers at experimental sites compared to before period	Graphs only.	0.53 (CI incalculable)	Warning versus post-intervention Specific months reported for Experimental sites (16 sites) Mean of months within phase for Controls % vehicles speeding.	Low
CA Toronto	A time halo effect lasted for 3 days following a single application of enforcement. With 5 days of consecutive enforcement a time halo of at least 6 days was noted. At the site of speed limit enforcement the average speed was reduced to around the posted speed limit. This reduction in average speed was seen to decay exponentially with distance downstream	Experimental data tabled. Control data graphed.	Not reported.	Experimental 3, enforcement site only. 5 consecutive enforcement days. Several pre and post occasions	High
*CA Vancouver	2.8 km/h reduction in mean speed at monitoring site, 2km from experimental site	Graphs for experimental site are unclear.	Not reported.	8 locations over 3 regions Monthly time series.	Moderate
*DE Germany	Reductions in median speed by 40 km/h and 28km/h in left and middle car lanes and 23km/h in truck lane on autobahn, sustained through 10 years of continuous enforcement. Also reductions in 85th percentile speeds of 42 and 37km/h in car lanes and 39km/h in truck lane	Medians graphed.	Medians graphed.	No control data reported. Cumulative speed distributions for pre-post reported	Low

*DK Denmark	During pilot program an overall 2.4 km/h reduction in mean speed with only small differences between the 3 cities. A 10.4% reduction in proportion of drivers exceeding the speed limit and a 4.5% reduction in those exceeding the speed limit by 10km	Not reported.	Not reported.	Enforcement and control and sites not graphed separately in English version	Low
*FI Finland	On 80 km/h sections an 8% reduction of speeding vehicles seen on experimental sites compared to control sites in year 1, with a further 2% decrease in year 2. On 100 km/h stretches a 5% reduction in number of speeders seen in year 1, with a further 2% reduction in year 2. Distance halo of 3 km upstream and 2 km downstream.	Only pre-post differences reported.	0.66 (CI incalculable).	Annual data for two years post. Two speed limits. Geometric means. Post=during	Low
*GB 30 MPH roads Nationwide	Reduction in mean speeds by an average of 4.4 mph, 85% percentile speed reduction of 5.9 mph and a 35% reduction in percentage over the speed limit. These reductions were comparable for all monitored lengths e.g. up to 250m, 500m and 1 km	insufficient comparison data information.	insufficient comparison data information.	62 fixed speed cameras, 57 speed sites, 61 speeding sites. Comparison = UK national averages. 3 pre, 3 post years data	High
*HK Hong Kong	65% reduction in speeding vehicles in excess of 15km/h or more, over the speed limit				Low

*NL Friesland	Mean speed reduction of 4 km/h on experimental roads compared to 1.5 km/h on control roads. A 12% reduction in percentage of drivers over the allowed speed limit on experimental roads compared to 5% reduction on control roads	0.97 (0.91-1.03)	0.68 (0.33-1.02)	Annual means. 1 pre 1 post occasion after 5 years. 12 experimental roads (1997 flow rate: 3800/24 hr) 15 control roads (1997 flow rate: 7200/24 hr) Speed limit =80km/hr	High
*NL Netherlands	Aggregation of data from the 4 roads in provinces (compared to phase 0) showed a reduction in average speed of 3km/h in phase 1 and 5km/h in phase 2, a reduction in 85 percentile speed of 3km/h in phase 1 and 8 km/h in phase 2. A reduction in proportion of speeders from 38.2% to 28% in phase 1 and from 38.2% in phase 1 to 11.4% in phase 2	0.936 (0.931 to 0.941)	0.43 (0.41 to 0.46)	Aggregate vehicle data for 4 provinces, 2 roads per province as reported in English version. Weighted mean speed and SD across two intervention phases. Aggregated PS for two intervention phases	Low
NO Oslo	Reduction in average speeds by 0.9 to 4.8 km/h for all times of day reported. 10% reduction in proportion of speeding drivers. A time halo effect of up to 8 weeks was shown	Graphs only. No control data reported.	Graphs only. No control data reported.	2 Speed limits 3 periods each day Weekly Time Series (2 pre, 6 during, 8 after)	High
NZ Nationwide	Average reduction in mean speed 2.3 km/h ($p = 0.05$) at camera sites post 1st year. Average reduction in mean speeds 1.3 km/h (-2.6 to 0.1) post 2nd year on experimental open roads	0.98 (CI incalculable) Also see ITS table	0.86 (CI incalculable)	June 1997 not included in RSR because of publicity effect. Weighted mean speed of post data used. Ticket rate used as proxy for proportion speeding	Moderate

US Arizona 2	At the Scottsdale sites mean speeds decreased from 70 mph to about 65 mph. At the non-Loop 101 sites (where no before data was available) mean speeds fluctuated between 68 and 69 mph. The proportion of vehicles in excess of the tolerated speed limit decreased from 15% in the before period, to 1-2 % in the post implementation period at the Scottsdale sites. These reductions were not sustained when the program ended	After 6 weeks enforcement:0.91 (CI incalculable) After 5 months enforcement: 0.93 (CI incalculable) After 8 months enforcement: 0.93 (CI incalculable) After end of enforcement:0.99 (CI incalculable)	No control data given	6 fixed cameras, 4 experimental sites. 4 control sites, during and post. Control Pre: ADOT. 5 data collection points:1 two months pre treatment, 3 occasions during intervention at 6weeks, 5 months and 8 months.1 six weeks post intervention 4 hrs per location; weekdays and Saturdays SL= 65 mph	Moderate
US Maryland	Mean speed at the 5 sites (where cameras were deployed) decreased by 10% (range 5% -18%) The proportion of drivers travelling > 10 mph above the speed limits declined by about 70% at locations with both warning signs and speed camera enforcement, 39% at locations with warning signs only and 16% on 40 mph residential streets with neither warning signs or speed cameras	Using Maryland controls 0.95 (CI incalculable). Using Virginia controls 0.90 (CI incalculable)	Using Maryland controls 0.52 (CI incalculable) Using Virginia controls 0.40 (CI incalculable)	8 mobile speed camera + 2 fixed speed cameras. duration: 6 months both pre and post. Means : speed and % speeding $\geq$ +10 mph. Means per site post treatment weighted for proportion of vehicles pre treatment. Speed limit 25-35 mph	Moderate
*US North Carolina	A 0.91mph significant reduction in mean speeds at experimental sites with a small insignificant reduction at control sites, 0.99mph significant	Day 0.99 (0.76-1.23) Night 0.98 (0.76-1.20)	Not reported.	Mobile speed cameras. 20 experimental sites from 14 corridors, 30 control sites from 11 corridors. Pre at 10 months pre camera, Post at 3 months	Moderate

	reduction in 85th percentile speeds at experimental sites with a small insignificant reduction at control sites. A significant 55% reduction in percentage exceeding speed limit by $\geq$ than 10 mph compared to little or no change at control sites			post camera installation. 4 year period (2000-2003), 2 times of the day: day and night. Variances pooled over sites, Means weighted over sites. Speed limits = 35, 40, 45, 55 mph	
US Washington DC	A significant 14% reduction in mean speeds compared to control sites. The proportion of vehicles exceeding the speed limit by more than 10mph decreased by 82%	0.852 (0.847 to 0.857)	0.35 (0.30 to 0.40)	7 experimental sites (SL: 25 - 30mph) 8 control sites (SL: 25 - 35 mph) Weighted mean and variance Sp: Formula for variance of ratios.	Moderate

BACKGROUND

The pandemic of road traffic deaths and injuries continues unabated. Each year almost 1.2 million people die and between 20 and 50 million people are injured or disabled worldwide as a result of road traffic crashes (Peden 2004). For people under 44 years, road traffic crashes are a leading cause of death and disablement second only to HIV and AIDS (Krug 2002). The continuing advance of motorisation in many developing countries is likely to further exacerbate the problem. It is estimated that by 2020 road traffic crashes will have moved from ninth to third in the world ranking of burden of disease, as measured in disability adjusted life years (Murray 1997). In 2003, the annual cost of road traffic crashes to Australia for example, was more than $17 billion per annum, or approximately 2.3% of Gross Domestic Product (GDP) (Connelly 2006). This finding is consistent with other recent reviews of the costs of road traffic crashes in developed countries (Elvik 2000; Jacobs G 2000) in which the mean costs have commonly been found to be in the order of 2-3% of GDP. Thus, the identification of effective strategies for the prevention of road traffic injuries is of public health and public finance importance globally.

The relationship between speeding and crash rate, and speeding and injury rate has been examined in many studies and reviewed by the US Transportation Research Board (US TRB 1998). The relationship between speeding and the likelihood of crashing should be logical; increasing speed increases the reaction distance (the distance travelled while the driver is reacting to a situation) and the braking distance. In reality, the relationship between speeding and crash rate is not simple, but it is consistent across studies. In two-car crashes, the greater the deviation in speed from the average, the higher the rate of crashes. This relationship is thought to be due to increased interactions between vehicles when travelling at different speeds. In single-vehicle accidents, the higher the speed, the greater the risk of crashing. Whilst studies demonstrate that motorists travelling at both significantly higher and significantly lower than average speeds have a greater crash risk, it has also been highlighted that the relationship with lower speeds was due mainly to crashes involving turning and slowing vehicles (US TRB 1998; Aarts 2006). The relationship between speeding and injury rate is straightforward; the faster the vehicle is travelling, the greater the energy absorbed by the occupants during the rapid change in velocity that occurs during a crash.

Speed limits on roads are used to regulate traffic speed and thus promote road safety by establishing an upper limit on speed, and by reducing the variance ('dispersion') of the speed of vehicles. As injury severity increases non-linearly in relationship to speed, curbing 'top-end' speeders should also reduce the number of deaths and severe injuries in those crashes that do occur. Speed limits are usually assigned by category, type, and design of the road (Chin 1999). The main purpose of speed limits is to regulate driving speeds to achieve an appropriate balance between travel time and risk (US TRB 1998). Many countries provide some type of enforcement to ensure that drivers obey the posted speed limits.

In Australia, during 2002, there were 1715 fatal crashes, of which 562 were identified as involving excessive speed (defined as driving faster than the posted limit or too fast for the prevailing conditions), using data obtained from the Australian Transport Safety Bureau (ATSB 2003). This finding is consistent with a 2004 report on fatality data from the United States which suggests that excessive speed likewise defined, is implicated in about 30% of all fatal crashes there (U.S. Department of Transportation 2004). It is predicted that, if the number of drivers who are speeding is reduced, both the likelihood and severity of a crash will be lowered (Pilkington 2002). The enforcement of speed limits must be sufficient to ensure that drivers believe that if they speed, they will be caught. Police cannot be present on all roads at all times and therefore, in many countries, there is increasing use of automatic speed enforcement, using detection devices (speed cameras) that may be manned or unmanned, mobile or fixed, as well as overt or covert. Most of the older speed camera systems rely upon 35 mm wet film, which necessitates regular extraction from the units, while the newer systems employ digital and video cameras and transmit the information over data networks. Most speed cameras use a low-powered doppler radar speed sensor that triggers the camera to photograph vehicles and capture the licence plate number of vehicles travelling above a preset speed. Automated speed enforcement cameras take single spot or average vehicle speeds over several measurements (Decina 2007).

Automatic speed enforcement has the capability of being a substantial net revenue-raising activity. This blurs the line for the public as to whether governments use the device for safety or for fiscal reasons, and may harden attitudes towards their use. Some people view the introduction of speed cameras as a violation of their civil liberties. Legal issues, such as whether the owner or the driver of a vehicle is responsible for the speeding violation, also arise. The arguments for and against speed cameras have been highlighted in British Columbia, Canada. The trial by (Chen 2000) concluded that the introduction of cameras had reduced speeding, with a corresponding decrease in crashes, injuries and fatalities. Nevertheless, in June 2001, the speed camera program was discarded by the incoming government. However, most countries that have introduced speed cameras have tended to expand their use over time. This is particularly noticeable within the United Kingdom and Australia.

The aim of this systematic review was to determine whether the use of speed detection devices reduces the incidence of speeding, crashes, injuries and deaths. A secondary consideration was to examine the relative effectiveness of covert versus overt cameras, halo effects, and mean and actual speeds. Little empirical evidence currently exists for the relative effectiveness of covert detection devices versus devices that can be seen. It is thought that while overt cameras should reduce speeds at road crash 'black spots' (also called 'hotspots'), covert cameras should reduce speeds over a wider area (Keall 2001). Likewise, other questions that need to be answered centre upon the so-called 'halo' effects. For example, the length of time an effect of enforcement is present after detection devices have been removed is known as the time-halo. The distance-halo is the distance from the point of speed enforcement that the decrease in speed continues. Regarding speed, speed cameras may lower the mean (relative) speed on the road (for example, the mean speed could fall from 110 km/h to 107 km/h in a 100 km/h zone), or they may lower the top speeds (absolute) on the road (for example, the top speed may be 150 km/h pre camera and 130 km/h post camera in a 100 km/h zone). This review considered both types of speed reduction.

To ensure the highest possible level of evidence available, in the absence of randomised controlled trials, studies selected for this review included only before-after trials with control or comparison areas and interrupted time series studies. This is in contrast to the only other systematic review of speed cameras (where standardised calculated results were reported) which included both controlled and uncontrolled before-after studies (Pilkington 2005).

O B J E C T I V E S

The objective of this systematic review was to investigate whether speed enforcement detection devices lower:

- the percentage of speeding drivers on the road;
- the absolute speeds above the speed limit;
- the rate and severity of injurious crashes on the road.

M E T H O D S

Criteria for considering studies for this review

Types of studies

Studies were included if they involved any of the following research designs:

- randomised controlled trials (RCTs) (including clustered RCTs and quasi-RCTs);
- controlled before-after studies (CBAs);
- interrupted time series studies (ITSs).

The definition of CBA and ITS designs are based on that used by the Cochrane Effective Practice and Organisation of Care group (EPOC) as follows:

- CBA: A design where there is contemporaneous data collection before and after the intervention and an appropriate control site or activity;
- ITS: A design where there is a clearly defined point in time when the intervention occurred and at least three data points before and three after the intervention.

All reasonable efforts were made so that the inclusion of trials was not restricted by language or publication status.

Types of participants

Drivers of all motorised vehicles.

Types of interventions

All automated and semi-automated methods and systems available for speed enforcement were considered. This included speed cameras (photo radar) laser and other radar devices as well as ancillary equipment such as road embedded electromagnetic loops. These types of interventions can be further categorised into either manned or unmanned; mobile or fixed, overt or covert cameras or a combination of these.
As the effect of co-intervention is difficult to exclude in studies such as these, studies that did not have the aforementioned speed enforcement devices as the major intervention focus were not eligible for inclusion.
This systematic review does not cover interventions by red light cameras at signalised junctions, as this topic has been addressed by another Cochrane systematic review, available from the Cochrane library (Aeron-Thomas 2005).

Types of outcome measures

- Percentage of speeding drivers above the speed limit or designated speed threshold, and their average speeds in areas with and without cameras: to investigate the overall effect of the enforcement.
- The absolute pre/post change in speed or the percentage pre/post change in speed in areas with and without cameras.
- Duration of speed reduction (i.e. time and distance halos): to investigate the local and widespread effects of the enforcement.
- Crash and injury outcomes: All road user deaths and injuries and all road traffic crashes. Our definition of 'road users' included drivers and their passengers, cyclists and pedestrians.

Search methods for identification of studies

The searches were not restricted by date, language or publication status.

Electronic searches

We used the following methods for identification of studies, searching mainly transportation, educational and medical electronic databases;

- Cochrane Injuries Group Specialised Register (April 2004 and June 2009)
- Cochrane Central Register of Controlled Trials and the Cochrane Database of Systematic Reviews (*the Cochrane Library)*
- MEDLINE (via WebSPIRS 1962 to May 2010)
- EMBASE (via WebSPIRS 1995 to May 2010)
- TRANSPORT (includes the Transport Research Information Services (TRIS), The International Road Research Documentation (IRRD) and The European Conference of Ministers of Transport (TRANSDOC) databases) (1968 to September 2009);
- Web of Science (Science (and Social Science) Citation Index 1981 to September 2009);
- PsycINFO (1980 to September 2009)
- CINAHL (1982 to September 2009)
- EconLit (1990 to November 2004)
- WHO database (1995 to November 2004)
- Sociological Abstracts (1995 to November 2004)
- Dissertation Abstracts (1990 to October 2004)
- Index to Theses (1985 to August 2009)

Search strategies are further reported in Appendix 1.

Searching other resources

Handsearches

We handsearched the journals Accident Analysis and Prevention (1974 to April 2010) and Injury Prevention (1995 to April 2010).

Internet searches

We searched the web sites of a number of road safety organisations, a full list is presented in Appendix 2.

We set up a daily Google Alert, now Giga Alert (April 2004 to June 2010). The following search words were found to be the most effective combinations, accounting for the greatest number of relevant 'hits':

- speed camera study
- automatic enforcement speed* study
- speed camera before after study
- speed camera before after control*
- safety speed camera trial study
- speed roads control* before and after study
- speed* camera* injury accident crash* speed camera road study
- speed camera halo effect, safety speed camera enforce*
- speed* camera* collision * crash* trial * speed* camera* injury*
- before after, study* speed* camera* police, safety camera enforce* control

The settings for Google Alert allowed these search words to be further utilised by restricting the search to different time frames and/or countries. Certain search words used for other databases such as photo radar and laser were quickly abandoned in Google due to the large amount of irrelevant and advertising materials they generated.

British Medical Journal (BMJ) customised alerts (weekly) was also set up using the search terms randomised controlled trials, controlled trial, before and after studies, speed or safety camera, road crashes, road injury and their related thesaurus terms.

Unpublished studies

In an effort to identify unpublished studies we contacted experts in the field and searched national registers for ongoing trials. We attempted to identify further potential published or unpublished studies by checking references of relevant articles, reviews and books and by contacting authors of relevant papers where possible. We contacted international and national road safety organisations as well as voluntary agencies with an interest in road safety. We also scanned daily newspaper and online news reports (for example, BBC news online (daily)) for references to relevant articles.

Conference proceedings

We searched the following conference proceedings

- Road Safety Research, Policing and Education Conference - www.rsconference.com:2004
- ICTCT International Co-operation on Theories and Concepts in Traffic Safety www.ictct.org/workshops/:2004
- RoSPA - Royal Society for the Prevention of Accidents http://www.rospa;2004
- Travelsafe Committee - www.parliament.qld.gov.au/committees/travel.htm:2004
- World Conference Injury Prevention and Control www.inspq.qc.ca/pdf/publications/InjuryPreventionControl2002.asp;
- Road Traffic Injuries and Health Equity Conference 2002 Massachusetts www.hsph.harvard.edu/traffic/papers.html;
- Road Safety on Three Continents Conference South Africa 2000 www.vti.se/pdf/reports/K15A.pdf;
- ARRB - Australian Research Board Conference 17th www.arrb.org.au:1994
- 7th World Conference on Injury Prevention and Safety Promotion Vienna 2004
- 9th World Conference on Injury Prevention and Safety Promotion Mexico 2008

Data collection and analysis

There were five stages of the review process.

Stage 1: Identification of studies for inclusion

One author (CW) initiated the original search for trials. A second author (CMW) continued the search, finding titles, abstracts and landmark reports in the road safety research literature. Based on potential relevance deduced from reading abstracts, full studies were obtained and short-listed if appropriate for assessment.

Stage 2: Selection of studies for inclusion

Relevant studies selected from the process in stage one were independently assessed against the inclusion criteria by three authors (CMW, CW, RLB). Investigators were contacted where possible for any additional information regarding trials that potentially fulfilled the inclusion criteria.

Stage 3: Data Extraction

Data were independently extracted from the included studies by four of the authors (CMW, CW, JH, RLB) using a standardised form, which was piloted before use. Data were extracted on the following key elements:

- study design;
- study length and data collection details;
- setting of the study and nature of the roads;
- types of interventions used;
- characteristics of intervention and control sites;
- measures of exposure and outcomes;
- description and treatment of bias and confounding;
- analyses and results.

Following data extraction, any differences or disagreements between reviewers were resolved by detailed discussion leading to consensus (CMW, CW, JH, RLB, NB). Where necessary and possible, additional information was sought from study authors.

Stage 4: Quality Assessment

The assessment of the quality of non-randomised trials is problematic. Controlled before-after studies (CBAs) and interrupted time series studies (ITSs) are acknowledged as methodologically weaker than randomised controlled trials, and few if any validated quality assessment instruments exist for non-randomised studies. Having perused the literature for validated tools, and discussed the issue at length with experts in the field, we decided to use a quality assessment process based on the Data Collection Checklist described by the Cochrane Effective Practice and Organisation of Care Review Group (EPOC).

Quality assessment and scoring was performed independently by three authors (CMW, CW, RLB). The process was based on four of the seven criteria used for the quality assessment for CBA designs, and the two additional criteria for ITS designs, used by EPOC. The criteria chosen were those that are relevant to community trial designs and specifically determine the appropriateness of baseline measurements, characteristics of the control site, protection against contamination between sites, and reliability of the outcome measures, including; objectivity of measurement, results being reported with random variability and p-values, important potential confounders and risk of bias described and controlled for, and discussion of study generalisability. ITS studies were also scrutinised against the EPOC quality criteria of a clearly defined point in time when the intervention occurred, and at least three data collection points before and after the intervention. All disagreements were resolved by consensus. Table 1 in the 'Additional Tables' section provides a list of the included studies with their individual quality grade.

Stage 5: Syntheses of results

In order to facilitate the comparison of studies as well as to capture the effect of intervention(s) and relate them to control (non-intervention) data, a standardised and well-defined summary measure was devised. These summary measures were calculated where possible i.e. if required information was reported or adequate data was available for calculation. The tool selected was based on relative effects, rather than difference in effect, where the outcome after intervention is divided by that before intervention as an expression of the proportional change in the outcome.

Unadjusted data provided by study authors in their tables, text or on graphs was used to present results in relation to speed, numbers speeding, crashes, injuries and fatalities.

In addition to study traits and outcome data in the 'characteristics of included studies' table, the results and further information were also presented in the Summary of findings for the main comparison and Summary of findings 2, which show speed and crash outcomes from CBA studies. These tables show the outcomes reported by the study authors' and also those calculated by our review author JH which consisted of standardised calculated results where possible and the study information that the latter were based on. Studies that reported both speed and crash results were highlighted with an asterisk in the tables. Summary of findings 3 show outcomes from the ITS studies consisting of the study authors' results, the outcome(s) analysed, statistical method, standardised calculated results where necessary (calculated by review author JH) and information that the latter were based on as well as quality grade.

CBA studies

The following descriptive summary statistics were used as the outcomes (speed and crash outcomes) for CBAs.

Speed

Relative speed ratio (RSR)

RSR = (average speed post intervention average speed pre intervention) (average speed post control average speed pre control)

When expressed as a percentage, RSR measures the relative percentage change in speed after intervention i.e. relative to control.

Percentage Speeding Relative Rates Ratio (PSRRR)

PSRRR = (speeding rate post intervention speeding rate pre intervention) (speeding rate post control speeding rate pre control)

When expressed as a percentage, PSRRR measures the relative percentage change in speeding rates after intervention i.e. relative to control.

This applied to the percentage of vehicles speeding or percentage of speeders who were speeding in excess of a speed threshold.

Crashes (all crashes, injurious crashes and fatal crashes)

Relative Crashes Ratio (RCR)

RCR = (crashes post intervention crashes pre intervention) (crashes post control crashes pre control)

When expressed as a percentage, RCR measures the relative percentage change in crash numbers after intervention i.e. relative to that for control. It is the same as the odds of crashing after intervention relative to the same odds if there were no intervention i.e. an odds ratio.

Percentage Crashes Relative Risks Ratio (PCRRR)

PCRRR = (crash risk post intervention crash risk pre intervention) (crash risk post control crash risk pre control)

When expressed as a percentage, PCRRR measures the relative risk of crashing post intervention, compared with pre-intervention, relative to that for control.

This applies to the percentage of vehicles crashing.

95% confidence intervals (CI) were included in parentheses. For all descriptive summary statistics, values less than 1 indicate a relative reduction, i.e. relative to control result. This reduction can be expressed as a percentage improvement using (1-summary statistic) x 100%.

In the case where the above descriptive statistics or CI were not supplied by the studies, but where there was sufficient other information, these were calculated. Statxact was used if data required exact methodology.

Weighted averages across strata were calculated unless weights were not supplied, in which case crude averages are used. Mean ratios were calculated using geometric means.

ITS studies

Interrupted time series analyses were conducted in six studies (AU VIC 1; CA British Columbia; ES Barcelona; GB Cambridge; GB Nationwide; NZ Nationwide). The statistical analytical method used for ITS studies ranged from simple monthly averages pre and post intervention to more advanced methods such as ARIMA or multivariate regression using generalised linear models. Within a study, these analyses were performed for different outcomes and for different constructs or strata. For both speed and crashes, most ITS studies reported a calculated or estimated percentage change in the outcome after intervention, which they commonly defined as,

(Post intervention estimate - Pre intervention estimate) x 100 Pre intervention estimate.

Meta-analysis was not appropriate for this review due to pronounced heterogeneity and consequently we could not test for publication bias. For the same reason, we were unable to perform any reasonable subgroup analyses on the various types of SEDs e.g. overt versus covert camera issues.

RESULTS

Description of studies

See: Characteristics of included studies; Characteristics of excluded studies.

After full text review of all potentially relevant studies, 35 studies met the inclusion criteria. All studies were observational in nature of which, 29 were controlled before-after trials (CBAs) incorporating a distinct control or comparison group(s) and six were interrupted time series studies (ITSs) with a comparison group(s). Seven studies had associated studies, which were subsumed in each of the seven primary studies. No randomised controlled trials were found.

As heterogeneity was widespread across studies we have included examples of variations in Table 2 in the 'Additional Tables' section of this review, to make it easier for the reader to note differences between studies.

Because several studies emanated from the same country and some studies had one or more main authors in common, it was decided that naming studies according to the official country codes of the International Organisation for Standardisation (ISO-3166) was the clearest naming option.

Nineteen studies reported both speed and crash outcomes (AU NSW 2; AU NSW 3; AU Tasmania; AU VIC 1; AU VIC 2; CA British Columbia; CA Vancouver B.C.; DE Germany; DK Denmark; FI Finland; GB 30mph Roads Nationwide; GB Nationwide; HK Hong Kong; NL Friesland; NL Netherlands; NZ Christchurch; NZ Nationwide; US Arizona 1; US North Carolina). Nine studies reported only crash outcomes (AU QLD 1; AU QLD 2; AU VIC 3; ES Barcelona; GB Cambridge; GB Norfolk; GB South Wales; GB West London; NO Nationwide) and seven studies reported only speed outcomes (AU NSW 1; AU South Australia; CA Toronto; NO Oslo; US Arizona 2; US Maryland; US Washington DC). Of the included studies, six studies reported halo effects, with three studies describing time halo effects (AU NSW 1; CA Toronto; NO Oslo) two studies reported distance halo effects (AU Tasmania; FI Finland) and one study (AU NSW 2) reported both time and distance halo effects.

Outcome measures in the studies differed considerably and included various definitions and measures of speed, crashes, injuries and deaths. For some studies, results for 'all crashes' may be inclusive of property damage crashes, and it should be borne in mind that injury crashes are not always necessarily a subset of those that are speed related (assuming such crashes can actually be defined). Most studies analysed crash numbers rather than rates and only a few studies provided data on the aggregate (over crashes) of the number of fatalities and number of people, who sustained at least one injury.

Types of interventions varied between studies. Speed enforcement detection devices (SEDs) were described according to whether they were overt or covert, whether they were operated from a fixed or mobile position on the road, or any combination of these four elements. For the purposes of this review, fixed SEDs were defined as speed cameras operating from a fixed mounted position on permanent poles and did not include speed cameras operating from patrol cars or working on temporarily installed poles. The latter, although stationary for a period were often moved from place to place. Seventeen studies assessed the effect of fixed cameras, of which, 16 studies had overt SEDs and one study had both overt and covert SEDs. Fifteen studies assessed the effect of mobile camera interventions. Of these, eight studies had overt and three had covert SEDs. Four studies had both a mixture of overt and covert SEDs. Two studies reported the effects from a combination of both fixed and mobile overt SEDs, and one study reported the effects of a combination of fixed, mobile, overt and covert SEDs.

Studies also varied considerably in both the number and duration of intervention events. Interventions were continuous in only two of the studies. Continuous operation was defined as SEDs operating continuously at all experimental sites and did not include SEDs operating continuously at some sites on a random alternating basis.

All included studies took place in high income countries, with one study each from Denmark, Finland, Germany, Hong Kong and Spain, two each from the Netherlands, New Zealand and Norway, three from Canada, five from the United States of America, six from the United Kingdom and 10 from Australia. Thirteen studies were conducted within an urban setting, six in a rural setting, seven occurred in a rural and/or a semi-rural location and nine studies were conducted within a mixed urban/rural/semi-rural environment. This diversity of study locations corresponded with a range of urban, semi-rural and rural speed limits within studies, that varied from 40 kilometres per hour (km/h) through 60 km/h, 80 km/h, 100 km/h and 110 km/h to corresponding speed limits in miles per hour (mph) in the UK and USA. Only eight studies described their criteria for speed limit compliance, above which traffic infringement notices were issued.

All included studies were published between 1984 and 2009, with study periods ranging from nine weeks to thirteen years; twelve trials had study periods of less or equal to 24 months, seven had study periods of 25 to 48 months (2+ to 4 years), nine had study periods of 49 to 72 months (4+ to 6 years), one of 73 to 96 months (6+ to 8 years), three of 97 to 120 months (8+ to 10 years) and three of equal or greater than 120 months (10 years plus). The major focus for studies of the shortest duration was the measurement of halo effects.

More detail about individual studies can be found in the table 'Characteristics of included studies'.

Risk of bias in included studies

Four of the seven criteria outlined in the data collection checklist described by the Cochrane EPOC Review Group were used to establish the methodological quality of the included controlled before-after studies:

1. availability of baseline measurements;
2. appropriate choice of control;
3. protection against contamination between intervention and control site;
4. reliability of outcome measures.

In addition to criteria 1) and 4) above, two other criteria as described by EPOC were used to assess the methodological quality of ITS studies, which were, a clearly defined point in time when the intervention occurred, and at least three data collection points before and after the intervention.

The criteria for CBAs provided twelve key indicators in total, and the criteria for ITS studies provided a total of nine key indicators.

The outcomes for the scoring method used to assess the methodological quality of the included studies can be viewed in Table 1. CBA studies were marked as either done, not clear, not done (as described by EPOC) for each of the twelve indicators, and again ITS studies were marked as either done, not clear, or not done for each of the nine indicators.

For studies to be then classified as high quality, moderate or low quality, the scoring was as follows;

CBA studies: High = (Done = 10, Not clear = 2, Not done = 0), Moderate = (Done = 8, Not clear = 2, Not done = 2), Low = (< 8 Done).

ITS studies: High = (Done = 7, Not clear = 2, Not done =0), Moderate = (Done = 6, Not clear = 2, Not done = 1), Low = (< 6 Done).

The overall quality of the studies was assessed as low to moderate. Of the 35 included studies, only 12 studies were scored as being of high quality. Of the remaining 23 studies, 12 were scored as moderate and 11 were scored as low.

See the notes section in the 'Characteristics of included studies' table for concerns with specific studies. Additional information can also be found in the 'Summary of findings tables'.

Effects of interventions

See: **Summary of findings for the main comparison** Summary of findings- Speed Oucomes (CBA's); **Summary of findings 2** Summary of Findings -Crash Outcomes (CBA's); **Summary of findings 3** Summary of Findings -ITS studies

Calculated summary statistics and brief descriptions of speed and crash outcomes were presented for individual trials where appropriate.

Speed

All studies reporting speed outcomes reported an absolute reduction in average speeds post intervention. Reductions were reported either as mean speeds, 'average speeds' or as median speeds. Most studies, thirteen in total, reported mean speeds (AU NSW 2; AU NSW 3; AU Tasmania; CA Vancouver B.C.; DK Denmark; GB 30mph Roads Nationwide; GB Nationwide; NL Friesland; NZ Nationwide; US Arizona 2; US Maryland; US North Carolina; US Washington DC). The reduction in mean speeds ranged from 1.3km/h in New Zealand to 5.8 km/h in New South Wales, with most countries showing reductions in the 2 to 4 km/h range. For countries expressing speed in miles per hour, the mean speed reduction ranged from 6% in the United Kingdom nationwide to 14% in Washington D.C. Average speeds were reported by three studies (AU VIC 2; NL Netherlands; NO Oslo) and showed speed reductions ranging from 0.9km/h to 5 km/h. Median speeds were reported by two studies (AU South Australia; DE Germany) with the former reporting a speed reduction of 5km/h and the latter recording reductions in median speeds of 40km/h and 28 km/h in car lanes, and a 23km/h reduction in the truck lane on the motorway after 10 years of continuous automated enforcement.

The standardised summary statistic relative speed ratio (RSR) that is, the relative percentage change in average speed after intervention i.e. relative to control could be calculated for nine of the studies (AU NSW 2; AU Tasmania; NL Friesland; NL Netherlands; NZ Nationwide; US Maryland; US Arizona 2; US North Carolina; US Washington DC). From these studies, fourteen RSR results could be calculated which ranged from 0.85 to 0.99, indicating that relative post-pre reductions were an improvement on 'control' i.e. control arm(s) by between 1% to 15%. For eight of the RSRs, there was insufficient information to calculate confidence limits (CL). Of the remaining six RSRs, using CL as an indication of statistical significance, two RSRs were significant and four non-significant (Summary of findings for the main comparison).

Percentage speeding

Speed was also reported as either absolute reductions in the percentage of speeding vehicles, as percentage speeding reductions over various speed limits, or as reductions in percentages of top end speeders. Eight standardised summary statistic percentage speeding relative rates ratio (PSRRR) could be calculated for eight studies (AU NSW 1; CA British Columbia; FI Finland; NL Friesland; NL Netherlands; NZ Nationwide; US Maryland; US Washington DC) and ranged from 0.35 to 0.86, indicating reductions of 14% to 65% relative to controls. For five of the PSRRRs there was insufficient information to calculate confidence limits (CL). Of the remaining three PSRRR's, using CL as an indication of statistical significance, two RSR's were significant and one non-significant (Summary of findings for the main comparison).

An absolute reduction in the proportion of speeding vehicles (drivers) over the accepted posted speed limit, ranged from 8% in Finland to 70% in New South Wales, with most of the twelve countries reporting this outcome, in the 10 to 35% range.

For the proportion of vehicles exceeding the speed limit by more than 10 mph, an 82% absolute reduction was reported in the (US Washington DC) study. The calculated PSRRR was 0.35 (95% CI 0.30 to 0.40) indicating that the reduction was a significant improvement over that for controls. The Maryland study (US Maryland) reported a 70% reduction; PSRRR 0.52 (CI incalculable) and the North Carolina study (US North Carolina) saw a 55% reduction (PSRRR incalculable) (GB Nationwide) reported a 43% reduction for vehicles exceeding the speed limit by more than 15 mph. For countries reporting in kilometres per hour the reduction for vehicles exceeding the speed limit by more than 10 km/h ranged from 4.5% in Denmark to an 88% reduction in New South Wales. Hong Hong reported a reduction of 65% for those exceeding the speed limit by more than 15 km/h and Victoria (AU VIC 2) saw a 76% reduction in vehicles exceeding the speed limit by more than 30 km/h post implementation of the speed camera program. Further details of speed outcomes can be seen in the 'Characteristics of included studies' section and in Summary of findings for the main comparison and Summary of findings 3.

Halo effects

Two important measures of the local effect of automated enforcement on the speed distribution are the time halo and distance halo. The effect of the distribution of speeds at and around the site of enforcement whilst the enforcement takes place is known as the distance halo. The time halo is the effect on the distribution of speeds after the enforcement activity has been terminated. As the characteristics of studies, where a primary focus was the reporting of halo effects varied in terms of location, duration of intervention, data collection and measurement, a brief overview of each of the six studies that reported these halo effects is as follows:

New South Wales (AU NSW 1) - Outcome = Time halo of at least two days.

Study period from February 1982 for a period of nine weeks.

Two experimental sites with police car stationed at both sites. The primary survey point was 300 metres downstream at site two where the experiment was covert. The secondary point was 200 metres upstream at site one, where the experiment was overt. The sites were in two lane sub-arterial urban roads with a 60km/h speed limit. Enforcement symbol in place and enforcement period was

for one hour in the morning 8.00am to 9.00am and one hour in the afternoon 2.00pm to 3.00pm in February and March 1982.
Oslo (NO Oslo) - Outcome = Time halo up to eight weeks during daylight hours, in 80 km/h zones three out of five measured time intervals showed a time halo effect of six weeks.
Study period August 1991 to December 1991.
Five patrols each consisting of one marked vehicle and two police officers, average nine hours of enforcement per day (388 hours of enforcement in six weeks). Continuous speed measurement for 24 hours every day during the sixteen week study period. Experimental road was a 35 km stretch of undivided two lane road in a semi-rural area divided into six sections for the experiment (control similar).
Toronto (CA Toronto) - Outcome = Three day time halo for one dose of enforcement.
At least six days time halo for five consecutive doses of enforcement.
Study period October 1979 to December 1979; five week study. Data collection by 2.5 hours per day on weekdays of five consecutive weeks for each location. Automatic speed traffic data recorders were used. Four experiments are described. The four experiments differed in the number of days of enforcement. Each experiment consisted of measuring speed of vehicles before, during and after enforcement took place. Each of the four experimental sites had an 'upstream' enforcement and a 'downstream' measurement site (latter was 1km to 2.5 km from the site of enforcement). In experiment 1 the police van was visible in advance. In experiment 2 to 4 the police vehicle was visible to the driver only 200 to 300m before passing the speed sensors.
New South Wales (AU NSW 2) - Outcome = Time halo at least one day after enforcement, distance halo up to 14 km downstream.
Study period December 1986 to March 1987 for speed.
Thirty-two sites of enforcement, aerial speed surveillance. From the 32 rural sites in place by December 1986, 10 experimental sites were chosen. Five matched control sites were selected.

Tasmania (AU Tasmania) - Outcome = Distance halo up to 22 km.
Total study length was two years between December 1984 to December 1986.
Single overt police car, random scheduling low intensity enforcement for two hours per day, seven days per week at sites. Location was three rural or main roads with a 110 km/h speed limit divided into one km sections.
Finland (FI Finland) - Outcome = Distance halo 3 km upstream to two km downstream. Study period April 1990 to December 1993. Cameras rotated randomly between 12 camera poles at a distance of 1.5 km to 7 km from each other in one direction of enforcement. Duration of surveillance from 8 to 36 hours (operation time 8065 hours from April 1992 to December 1993).

Crashes

All studies reported a reduction in road traffic crashes and crashes resulting in injury post speed camera intervention. The magnitude of this effect in crash outcomes varied considerably across studies. Crash outcomes were reported by twenty eight studies in total, of which, localised effects (that is, at or in the vicinity of camera sites) were reported by eleven studies. Twenty studies reported on generalised effects and three of the twenty eight studies reported both localised and generalised effects.

Localised crash effects

The result for 'all crashes' showed pre/post percent reductions ranging from 8% in Victoria (AU VIC 1) to about 49% in Arizona (US Arizona 1) with all other studies reporting this outcome showing reductions in the 14% to 25% range. For crashes resulting in deaths or serious injuries pre/post percent average reductions of 11% at or less than 500m distance and 13% at or less than 1km distance were reported by (GB 30mph Roads Nationwide), reductions of 11.5% were seen in Victoria (AU VIC 2) and reductions of 38%, 42% and 44% were reported by (AU QLD 2; GB Nationwide and GB Norfolk) respectively. Whilst a pre/post reduction of 22% in personal injury crashes at camera sites was found in one large study in (GB Nationwide) no significant reduction in injury crash frequency or severity was found within one km of camera sites, either in urban or rural areas, in another sizeable study in Victoria (AU VIC 1) as a result of camera site operations. However in this latter study a localised effect of 8.4% in pre/post injury crash reduction was found for all urban roads as a result of the influence of receipt of traffic infringement notices (TINs). A reduction of about 50% in injury crashes was reported by South Wales (GB South Wales) and the Cambridge study (GB Cambridge) reported a pre/post 45.74% reduction in injury crashes within 250m from camera sites and a lesser but significant 20.86% reduction inside a 2 km radius from the camera.

Generalised crash effects

Outcomes reported were pre/post reductions in 'all crashes' ranging from 9% in Christchurch (NZ Christchurch) to 35% in the Netherlands (NL Netherlands), with all other studies reporting reductions in the 11% to 27% range. For crashes resulting in death or serious injury pre/post percent reductions ranged from 17% in British Columbia (CA British Columbia) to 58% in Tasmania (AU Tasmania) with all other studies reporting this outcome in the 30% to 40% reduction range. For injury crashes pre/post percent reductions ranged from 17% in British Columbia (CA British Columbia) and New Zealand (NZ Nationwide) to 23% reductions for Denmark (DK Denmark) and Hong Kong (HK Hong Kong).
For the outcome 'all crashes' 14 relative crash ratio (RCR) could be calculated for 12 studies and ranged in value from 0.53 (95% CI = 0.39-0.73) in Arizona (US Arizona 1) to 0.95 (95% CI = 0.73-1.22) in Vancouver (CA Vancouver B.C.) denoting reductions of

5% to 47% for 'all crashes' relative to controls. Using CL as an indication of statistical significance, eight RCRs were significant and six were non-significant. The RCR could be calculated for 11 studies reporting 'injury crash' results and ranged from 0.57 (95% CI = 0.32-1.03) in Arizona to 0.86 (95% CI =0.42-1.02) in Hong Kong (HK Hong Kong), of which two were significant and nine non-significant. For the few studies (4) where the RCR could be calculated for 'fatalities', the result ranged from 0.00 (95% CI =0.00-0.35) in New South Wales (AU NSW 2) to 0.72 (95% CI = 0.36 -1.08) in Tasmania (AU Tasmania). In the (GB 30mph Roads Nationwide) study both fatal and serious injury crashes were reported together. The RCR in this latter study, for at or less than the 500km distance was 0.69 (95% CI = 0.57-0.69) with an RCR 0.73 (95% CI = 0.53-0.93) calculated for $\leq$ 1km distance from camera sites. Using CL as an indication of statistical significance, three of the five RCRs were significant and two non-significant. Only one study (DE Germany) gave enough information to calculate the summary statistic percentage crash relative rates ratio (PSRRR), which was 0.44, CI incalculable. In summary, of the 30 RCRs calculated, 13 were significant and 17 were non-significant.

Further details of crash outcomes can be seen in the 'Characteristics of included studies' section and in Summary of findings 2 and Summary of findings 3.

Interrupted time series studies

Interrupted time series analyses in this review were reported with both speed and crash outcomes for six countries (AU VIC 1) Phase I and II; state-wide and metropolitan); (ES Barcelona; GB Cambridge; GB Nationwide; NZ Nationwide) with the British Columbia study (CA British Columbia) also reporting some time series data. The statistical analytical method used ranged from simple monthly averages pre and post intervention to more advanced methods like ARIMA or multivariate regression using generalised linear models. Within a study, these analyses were performed for different outcomes and for different constructs or strata. Most studies reported results as estimated percentage changes in the outcome after intervention and the results can be viewed further in Table 3. Times series analysis was also used to analyse the headcount of crash victims. CA British Columbia estimated a drop in crash victims of -31 to -140, while NZ estimated percentage changes in casualties, compared with control, of -19% and -31%. It was noted in AU VIC 1 (Phase 2), the ratio of fatal plus serious crashes to minor crashes (severity), was analysed using a multiplicative model. Significant reductions in crashes were reported (p<0.01) on a log scale linked to increases in traffic infringement notices (TINs) issued and increased publicity, whilst significant reductions in severity were attributable to increases in TINs issued and hours of speed camera operation. Further details for interrupted time series studies can be seen in the 'characteristics of included studies' and in Summary of findings 3.

ADDITIONAL SUMMARY OF FINDINGS [*Explanation*]

Study ID	Main Outcomes (Reported by Study Authors)	Crashes (Review Authors)	Injuries (Review Authors)	Fatalities (Review Authors)	Results based on	Quality of the evidence (Grade)
	* denotes studies reporting both speed and crash outcomes.	*Relative crashes ratio (RCR) with (95% CI) or % crashes relative risk ratio (PCRRR) with (95% CI)*	*Relative crashes ratio (RCR) with (95% CI) or % crashes relative risk ratio (PCRRR) with (95% CI)*	*Relative crashes ratio (RCR) with (95% CI) or % crashes relative risk ratio (PCRRR) with (95% CI)*		
*AU NSW 2	23% crash reduction during the day and a 21% reduction at other times	RCR = 0.78 (0.59 - 1. 05)	RCR = 0.81 (0.53 to 1. 24)	RCR = 0.00 (0.00 - 0. 35)	Aggregate of monthly counts. Formula for fatalities based on exact methods	High
*AU NSW 3	Aggregate changes in crashes showed an insignificant 19.7% reduction in all reported crashes with a 20.1% reduction in injury crashes and an 89.8% reduction in fatal crashes along camera segments	No control data reported.	No control data reported.	No control data reported.		Low
AU QLD 1	A significant 11% reduction in total crashes outside of city. Estimated 31% reduction in fatal crashes	Not reported.	Not reported.	Not reported.	% differences estimated from model.	Low
*AU QLD 2	Greatest crash reductions in areas within 2km of camera sites, with 31% (1100), 39% (2200), 19% (500) and 21% (1600) reductions estimated for hospitalisation, medically	Not reported.	Graphs only.	Graphs only.	3 SLs (60, 70 and 100km/ hr). Fatal and hospitalisation crashes are combined for the ‘ ‘ fatal” result	High

	treated, other injury and non-injury crashes respectively					
*AU Tasmania	A significant 58% reduction in serious or fatal injury crashes	RCR = 0.88 (0.75 - 1.02)	RCR = 0.78 (0.64 - 0.93)	RCR = 0.72 (0.36 - 1.08)	Based on means per year for pre and for post period. Formula for variance of ratios	Low
*AU Vic 2	An estimated 7% reduction in overall injuries, 10% reduction in serious injury, and a 13% reduction in fatal crashes was reported	Not reported	Not reported	Not reported		High
Au Vic 3	A net reduction of 71.3 % (p = 0.064) in injury crashes up to and including 4 days after the presence of enforcement. A net reduction of 73.9% (p =0.045) on the day when a mix of overt/covert enforcement employed	Not reported	RCR =0.98 (0.84-1.14)	Not reported	2 periods, 3 types of enforcement	Moderate
*CA British Columbia	A 25% reduction in expected crash rate, 11% reduction in injury crashes and a 17% reduction in daytime crash fatalities	Graph estimates only. Time series -see ITS table.	Graph estimates only. Time series - see ITS table.	Graph estimates only. Time series -see ITS table.		Low
*CA Vancouver	A reduction of 16% (+/-7%) in expected crashes along study corridor. A 2.8km/h reduction in mean speed at monitoring site	RCR = 0.95 (0.74-1.22)	Not reported.	Not reported.	Aggregated counts at 8 locations over 3 regions.	Moderate

*DE Germany	Personal injury crash frequency reduced by a ratio of 1:1	Not reported for control pre intervention.	PCRRR = 0.44 (CI incalculable)	Not reported for control.	1 year post introduction of radar (1973) cf 2 years pre SL, but post addition of 3rd lane (1970, 1971) . RCR - data not available for control	Low
*DK Denmark	A 22% reduction in injurious crashes in first year and 20% in second year post intervention compared to before	Not reported.	Not reported.	Not reported.	Enforcement and control data is not reported separately in English version	Low
* FI Finland	A non-significant 19% reduction in crashes (not defined) A 20% reduction in injury crashes 2 years post intervention	Not reported.	RCR = 0.81 (0.48 to 1. 35)	Not reported.	Aggregate counts. 24 months pre, 21 months post. Two speed limits. Post = during. SE is a biased conservative estimate	Low
*GB 30 MPH Roads Nationwide	After accounting for all potential confounders, the overall average effect of speed cameras on crashes was a reduction of 25% in personal injury crashes (PIA's) and an average 11% reduction in fatal and serious crashes for the 500m monitoring length, with a similar average 24% reduction in PIA's and 13% reduction in fatal and serious crashes at the 1km length	≤500m RCR = 0.71 (0. 59-0.83) ≤1Km RCR= 0.76 (0.64-0.88)	≤500m Not reported. ≤1Km Not reported.	≤500m including serious: RCR= 0.69 (0.57-0. 82) ≤1Km including serious: RCR =0.73 (0.53-0.93)	62 fixed speed cameras, 57 speed sites, 61 speeding sites. Speed limit 30 mph. 3 pre years, 3 post years, 3 distance bands. 2 cumulative distance bands: ≤500m,≤1Km. comparison data is estimated from UK national averages, pre and post	High

GB Norfolk	At camera sites a reduction of 19% for all crashes and a reduction of 44% for fatal and serious crashes. The authors state that the reduction in total crashes was significantly greater than that expected from the effect of RTM in 12 out of the 20 experimental sites tested	RCR = 0.82 (0.68-0.99)	Not reported.	Not reported.	Aggregate Counts. Injury and fatality counts not separated. 24 months pre and post. 29 experimental sites, 72 km total. Control specification unclear. Variable speed limits, mostly non-urban	High
GB South Wales	Reduction of 50% in personal injury accidents (0-500m route)	Not reported.	Neither reported nor calculable.	Not reported	RCR based on control (post, pre) and experimental (pre) only	Low
GB West London	A significant 56% reduction in fatal crashes relative to controls, a 12% reduction for all crashes and a 25% for serious crashes	incalculable	incalculable	Incalculable	Control data not provided. % change relative to control is not defined in text.	Low
*HK Hong Kong	23% reduction in number of injury crashes. 66% reduction in fatal crashes	RCR = 0.74 (0.54 to 1.02)	RCR = 0.86 (0.42 to 1.76)	RCR = 0.33 (0.01 - 4.60)	Exact confidence limits for fatal crashes are calculated using STATXACT	Low
*NL Friesland	Aggregate change in crashes was a significant 12% reduction for experimental roads	RCR =0.79 (0.66-0.95)	Not reported.	Not reported.	Aggregate annual counts, 8 pre, 5 post occasions. 23 intervention roads, speed limit =80 km/h; 5 intervention roads, speed limit =100km/h. unspecified number of control roads. Total experimental road length =3428 km, total control road length	High

					= 5200 km	
*NL Netherlands	A reduction of 35% in the total number of crashes for phase 1 and 2 compared to the control roads and the same period 3 years previously	RCR = 0.64 (0.44 - 0. 91)	RCR = 0.66 (0.26 - 1. 61)	Insufficient data.	Aggregate crash data for provinces, 2 roads per province as reported in English version (Overijssel excluded). Aggregates over 3 pre periods. Exact confidence limits of Common log odds ratio for Post/Pre using STATXACT	Low
	Phase 3 - conducted in 1994 on one road in one province Noord-Brabant. The reduction in crashes found in 1991 had been maintained	RCR = 0.64 (0.45 - 0. 92)	RCR = 0.79 (0.31 - 2. 04)	Insufficient data.	Aggregates over 3 pre and 3 post periods. Aggregates for two control sites.	
NO Nationwide	A significant 20% reduction in injury crashes equating to about 62 injury crashes per year on all 64 road sections combined	Not reported.	RCR = 0.79 (0.72 - 0. 88)	Not reported.	Aggregate counts. 5 Speed Limits. 4 traffic scenarios.	High
NZ Christchurch	Reduction of 9.17% in crashes and a significant 32.4% in serious injury compared to New Zealand overall	RCR = 0.91 (0.80 - 1. 03)	RCR = 0.69 (0.48 - 1. 00)	Not reported.	Injuries = Serious + fatal.	Moderate
US Arizona 1	Total crash reduction at enforcement zones of 44 to 55%, injury crash reduction of 46 to 56% with no reduction seen in rear-	RCR = 0.53 (0.39 - 0. 73)	RCR = 0.57 (0.32 -1.03)	Not reported.	Aggregate counts. Pre (1651 days) Post (244 days) Intervention = 6.5 mile length, Control = 48 miles. Non-peak period	High

	end crashes					
US North Carolina	Total aggregate crash reduction of 12% on experimental corridors	Day: RCR 0.84 (0.7- 0.93) Night: RCR 1.04 (0.85-1.28)	Day: RCR 0.78 (0.53-1.15) Night: RCR 0.75 (0.40-1.40)	Day inestimable, no crashes post Night inestimable, no crashes post	14 Experimental corridors 20 sites. 11 Control corridors 15 sites. Pre: January 2000-July 2004 (55 months) Post:September 2004-December 2004 (4 months) night and day data. Speed limits =35, 40,45, 55 mph	Moderate

Study ID	Main Outcomes Types Reported	Outcome measure	Method used	Results (95% CI)	Results based on	Quality of the evidence (Grade)
AU VIC 1 (Phase one-Statewide)		Outcome = % vehicles speeding over threshold. Measure = % vehicles speeding over threshold on three monthly occasions	Graph of monthly data from June 1990 to January 1991	a) -11.3% b) -15.4% c) -8.0%	a) July 1990 b) May 1991 (increase in speed camera use begins) c) October 1991	High
Statewide	Phase 1 - General effects - effect of speed camera program on crash rate and severity covering first twelve month post intervention period. Phase 3, 4 and 5, of this 5-phase study did not have before-after data, hence only phase 1 and 2 tabled	Outcome = crashes (fatal, serious and minor) Measure = Estimated difference in the percentage change in crashes between experimental and control areas	ARIMA and multiple regression, using multiplicative models and natural logs	a) -9.7% (-19.1% to + 0.8%) b) -22.2% (-31.3% to - 11.8%) c)-17.9% (-27.9% to -6. 6%) d)-15.6% (-31.5% to + 4.0%)	Multiple regression a) Low level trial period b) Intervention period c) Enforcement - no cameras in control areas d) Enforcement - cameras in control areas.	
Metropolitan		Outcome = % vehicles speeding over threshold Measure = % vehicles speeding over threshold on three monthly occasions	Graph of monthly data from June 1990 to January 1991	a) - 15.8% b) - 8.0%	a) May 1991 (increase in speed camera use begins) b) October 1991	
Metropolitan		Outcome = crashes (fatal, serious and minor) Measure = Difference in the estimated percentage change in crashes between experimental and control areas	ARIMA and multiple regression, using multiplicative models and natural logs	a) -6.7% (-17.7% to + 5. 9%) b) -20.2% (-31.1% to -7. 6%) c) -12.7% (-25.4% to +2. 1%) d) -3.3% (-24.0% to + 23.1%)	Multiple regression a) Low level trial period b) Intervention period c) Enforcement - no cameras in control areas d) Enforcement - no cameras in control areas	

AU Vic 1 (Phase 2) Metropolitan(A)	Phase 2 - Impact of program mechanisms i. e. number of traffic infringement notices (tin's) hours of speed camera operations, amount of paid TV publicity, demerit points in relation to, injury crash incidence and severity during low alcohol times of the week, across the first 2 year post intervention period	Outcome = crashes (fatal, serious and minor) Measure = Log (crashes)	Multiple regression, using multiplicative models and natural logs	a) -0.0065 (-0.0101 to -0.0029) b) -0.0043 (-0.0119 to 0.0034) c) -0.0077 (-0.0128 to -0.0026)	a) Log (TINs issued) b) Log (Speed camera hours) c) Log (All publicity)	High
Metropolitan(B)		Outcome = crashes (fatal, serious and minor) Measure = Log (ratio of fatal & serious to minor, crash numbers)	Logistic (multiple) regression, using multiplicative models and natural logs	a) -0.0183 (-0.0284 to -0.0082) b) -0.0371 (-0.0572 to -0.0169) c) -0.0019 (-0.0189 to 0.0150)	a) Log (TINs issued) b) Log (Speed camera hours) c) Log (All publicity)	
CA British Columbia	Proportion of speeding vehicles in May 1996 (before) at photo radar sites was 66%. By July 1997 (after) it was about 35%. At control sites speeding vehicles in September 1995 was about 73%, in November 1996 it was about 61%	Outcome = mean speed Measure = estimated difference in mean speed post intervention	Cross-sectional time-series analysis	-2.4km/hr (-3.23 to -1.52)	a) 19 sites b) 15 monthly mean speeds c) Intervention after post-warning phase.	Low

	About 25% reduction in crashes to that expected. A significant 11% reduction in number of victims, with an average decrease of 139 daytime traffic crashes requiring an ambulance. A 17% reduction in daytime crash fatalities	Outcome = crashes Measure = estimated difference in the number of crashes per month post intervention	ARIMA	b) -54 (-113.0 to 5.7) c) -151 (-202.1 to -101. 8)	a) Speed related daytime crashes- principally property and minor injuries. b) Warning letters intervention. c) Violation ticket intervention.	
		Outcome = victims Measure = estimated difference in the number of victims per month post intervention	ARIMA	b) -31 (-119.1 to 57.1) c) -140 (-206.9 to -72.2)	a) Daytime victims carried by ambulance. b) Warning letters intervention. c) Violation ticket intervention.	
ES Barcelona	Outcome measures were numbers of road crashes, numbers of people injured (combined fatal and non-fatal) and number of vehicles involved in crashes. The relative risk of a road crash after implementation was 0.73 (5% CI = 0.63, 0.85) This effect was greater during off-peak traffic flow at weekends. Attributable fraction estimates for the 2 years of the speed camera intervention showed 364 crashes prevented, 507 fewer people injured and 789 fewer vehicles	Outcome = crashes (all types) Measure = Relative Risks (RR). Converted to percentage change in crash estimates	Intervention: Beltway (24. 1 km) 60 -80 kph. Controls: Arterial roads (43. 4 km) usually 50 kph. 8 fixed cameras -22 sites, Montly data -Pre 27 months, post 24 months. Poisson regression modelling	a) Approx 0% (CI not reported) b) -27% (-37%to -15%) c) -27% (-19% to -12%) d) -28% (-48% to -1%) e) -34% (-54% to -6%) f) -25% (-38% to -9%)	a) Arterial roads (Control) b) Beltway (Intervention) All crashes c) Beltway (Intervention) Day (commuter) d) Beltway (Intervention) Night (non-commuter) e) Beltway (Intervention)Weekdays f) Beltway (Intervention) weekends	High

	involved in crashes					
GB Cambridge	A 45.74% reduction in weighted injury crashes within 250 metres from camera sites (total monthly before count of 23.4 compared to total monthly after count of 12.7) with lesser but still significant decreases observed in the wider surrounding areas, such as, a 20.86% reduction inside a 2000 metre radius from the camera	Outcome = Crashes Measure = Percentage change in crash estimates.	Manual adjustment for time series effects and regression to mean	-34.9% (CI incalculable)	Average over 4 catchment areas.· Average of pre and post estimates over sites. All injury crashes.	Moderate
GB Nationwide (4 year evaluation)	Speed outcomes measured: Mean speed, 85th percentile speed, percentage of vehicles over the speed limit and percentage exceeding the speed limit by more than 15mph. Speed results across all new camera sites included a 2.3mph reduction (6% reduction) in mean speed,	Outcome=Speed, Measure = Percentage change in mean percent per site	33 localities,1943 sites, 6275 visits. Several varying number of monthly visits. Fixed and mobile speed cameras. no comparison sites for speed. Weighted averages. Post-pre difference as a % of pre. No statistical modelling	a) -5.7% (CI incalculable) b) -15% (CI incalculable) c) -3% (CI incalculable)	a) All cameras, weighted mean speed over 1943 sites b) Fixed cameras, weighted mean speed over 499 sites c) Mobile cameras, weighted mean speeds over 1442 sites	Moderate
	A 30% reduction in vehicles exceeding the speed limit, and a 43% reduction in vehicles exceeding the speed limit by more than 15 mph. Time over distance cameras were shown to be par-	Outcome = % exceeding speed limit. Measure =Percentage change in mean percent per site		a) -31% (CI incalculable) b) -70% (CI incalculable) c) -18% (CI incalculable)	a) All cameras weighted mean percent over 1943 sites b) Fixed cameras, weighted mean percent over 499 sites c) Mobile cameras, weighted mean percent over 1442 sites	

	ticularly effective (around 100% reduction) at reducing speeds exceeding 15mph over the speed limit					
	Crash outcomes measured: Killed and seriously injured (KSIs) and personal injury crashes (PICs). Across all sites KSI's decreased by 42%. This equated to about 1700 fewer KSI's per annum at these camera sites. Fixed cameras in both urban (47% reduction) and rural areas (62% reduction) were more effective than mobile camera sites in urban (35% reduction) and rural areas (34% reduction) at reducing KSI's. Across all sites PIC's decreased by 22%. This equated to a reduction in PIC's of about 4200 at camera sites	Outcome = Crashes (personal injury crashes PICs) Measure =Estimated percentage change in crashes above the national long-term trend of 1.5%	Aggregate counts over all sites and speed cameras for each of 38 localities, 4401 sites (urban or rural) Fixed cameras (standard, digital, red light) Mobile cameras 3 years pre period, varying post period lengths. Log-linear modelling/Poisson process	a) 22.3% (-24.3 to -20. 6%) b) Urban: -22.4% (-24.3% to -20.6%) Rural: -33.2% (-38.6% to -27. 4%) c) Urban: -22.4% (-23.9% to -20.8%) Rural: -15.5% (-18.8% to -12. 0%)	a) All cameras at 3530 sites b) Fixed cameras at 2409 sites c) Mobile cameras at 1992 sites	
NZ - Nationwide	Over the first 2 years of the study mean speeds fell by 1.3 km/h (-2.6 to 0.1) and 85th percentile speeds reduced by 4.3 km/h on open roads generally,compared with the rest of the country	Outcome = speed Measure = Difference in change in mean speed between experimental and comparison areas	Weighted averages, using time period and unidirectional hypothesis	a) -1.3km/hr (-2.6 to 0. 1) b) -2.3km/hr (-3.1 to -1. 4)	a) All experimental roads (post 2 year average) b) Speed camera sites (post 1st year average)	Moderate

	Having controlled for season and general trends, injury crash outcomes in experimental areas relative to control areas were a net reduction of 11% (p= 0.03) in all crashes and 19% (p=0.002) in injury crashes on open roads across the region associated with the covert cameras, over and above the effects of the existing speed camera program. At speed camera sites reductions of 17% for crashes and 31% for injury crashes was reported	Outcome = Crashes Measure = Estimated percent change of trial to control crash ratio	Logistic model of proportion of crashes in trial region cf control region, including season and year - unidirectional hypotheses	a) -11% (-20% to - 1%) b) -17% (-36% to +7%)	Change is in first two years of intervention. a) All roads b) Speed camera roads.
		Outcome = Injury crashes (fatal + serious) Measure = Estimated percent change of trial to control injury crash ratio	Logistic model with over-dispersion model of proportion of casualties in trial region cf control region, including season and year -unidirectional hypotheses	a) -19% (-28% to -9%) b) -31% (-50% to -3%)	Change is in first two years of intervention. a) All roads b) Speed camera roads.

DISCUSSION

Research conducted to date consistently shows that speed cameras are an effective intervention for reducing road traffic injuries and deaths. The methodological quality of the included studies in this review was at best moderate. Only twelve of the thirty five studies reviewed were categorised as being of high quality (Table 1) in the 'additional tables' section. A previous systematic review also noted the 'weak level of evidence available' (Pilkington 2005). However it was noted in this review that, in general, some of the more recent studies were conducted with greater methodological rigour.

Whilst randomised controlled trials offer the highest level of evidence, we found no studies using this study design. In an effort to account for local variation, we only included studies in this review that also had control or comparison areas with acceptable before and after study periods. With the exception of studies of short duration, whose outcome focus was the evaluation of speed and/or halo effects, all the included studies collected at least one year of 'before 'data and one year of 'after' data, with fourteen studies having at least two years of 'before' data and a follow-up period of at least two years.

Assessment of the quality of non-randomised controlled trials is problematic. After an extensive review of the quality tools available, we decided a modified version of the quality assessment process, as developed by the Cochrane Effective Practice and Organisation of Care Review Group best suited the evaluation of the studies under review. It is well known that the number of potential confounding variables in road safety evaluation studies is very large. Although we looked for how studies controlled or adjusted for any confounding variables, in regards to risk of bias and potential confounders, our main focus was on three variables known to be particularly important in road safety evaluations i.e. regression to the mean, long term trends and changes in traffic volumes (Hauer 1997).

Random fluctuations in recorded number of crashes occur in the long-term. Speed cameras are most frequently introduced at sites based on their more recent history of high rates of speed related crashes. However, it is possible that these crash frequencies were at the high end of naturally occurring random fluctuations, and that in due course crash numbers would regress back to the mean. We checked whether studies had controlled for regression to the mean (RTM) and for those which did not take it into account, we assessed where possible, if it was likely to be an important source of bias. Only ten studies out of a probable twenty four studies, where RTM may have been a sizeable factor, either described and/or controlled for its effects. Some of these ten studies used Empirical Bayes (EB) statistical methods to control for RTM, and this procedure has been suggested as the ideal standard method that future studies should employ (Hauer 2002; Decina 2007). Likewise, only a small number of studies controlled for other long term trends in crash rates and changes in traffic volumes. For example, the examination of possible traffic or crash migration to non-enforced routes is important. This is more likely to occur with fixed overt speed cameras. There is a need for better vehicle exposure/traffic volume data collection over time, so that noteworthy changes can be incorporated when analysing the effects of road safety programs. This is particularly important in light of the fact that studies available in this field have a quasi-experimental design, where the adequacy and appropriateness of comparison/control areas is often questionable. Regarding other possible effects on speed or crashes such as season, time of day, changes in road design, speed limits, and levels of road safety publicity, most studies only controlled for, or described a few of these, if any. No studies provided a rationale for the type of automated enforcement chosen in their particular case. Whilst resource costs are always a consideration, it would enhance the road safety evidence base if studies provided a comprehensive rationale for both the type and number of interventions chosen and their justifications for the length of study and amount of data collected.

We would have liked to have seen much more information on the comparison/control sites to help us judge how well the experimental and control sites were matched. With the exception of a few studies, much of this information was missing. A couple of studies reported that it is difficult, if not impossible, to find matching controls in some places, especially where the use of speed cameras is widespread and in operation for periods greater than ten years. In the United States, where automated speed enforcement is not yet widespread, in contrast to many European countries and Australasia, there is still an opportunity to conduct well-designed studies.

There was considerable heterogeneity across studies involving variations in speed limits, types and duration of interventions, length of follow up periods, setting of interventions, numbers of intervention and control sites and outcome measures. These factors made it difficult to integrate and summarise the evidence. We could not evaluate publication bias due to heterogeneity. However it is reasonable to expect that if any published negative studies existed, they would have received a high degree of publicity, considering the ongoing controversial nature of the debate surrounding speed cameras, in high income countries (Pilkington 2005). In relation to statistical analysis, methods used varied from the application of basic univariate analysis through to more rigorous statistical methodology for interrupted time series data. In some instances authors had developed in-house methods for analysing their data. Furthermore, the way in which results were reported varied extensively across studies, and one of the difficulties we faced was finding the basic information needed to calculate a standardised summary statistic in an effort to compare studies. It is recommended that there be some international consensus as to the expression of outcomes, for example, crash rates per volume of traffic; percentage pre/post changes in speed and percentage pre/post changes relative to controls, all with the accompanying 95% confidence intervals. Until this occurs meta-analysis is not possible. Realistically some heterogeneity will persist across studies as researchers need to work in conjunction with government and local authorities to address such issues as speed limits, road design, traffic flow, co-interventions. At analyses stage, statistical models can be adjusted for these factors. Heterogeneity can also be dealt with by the use of sub-group analysis. However, this opportunity is dependent on the collection and provision of high quality and detailed data.

In light of the differences between studies, to critically appraise the results from the 35 studies in this review we examined certain issues which are relevant to making inferences about treatment effects. To this end, we examined the 'signal to noise effect' (Glasziou 2007) and the criteria espoused by Austin Bradford Hill (Hill 1965) to determine the strength of inferences.

The determination of speed camera effect on speed, speeding and crashes is made difficult because traffic volume and speed are not stable but fluctuating, resulting in different degrees of signal to noise on any given road as well as from one road to another. Decreases in average speed, percent speeding and crashes after the introduction of speed cameras were consistently reported across the studies, which strengthens the evidence of a treatment effect. However the magnitude of the effect was variable, ranging from 8% to 70% reductions for speeding over the posted speed limit, 43% to 65% for exceeding the speed limit by 15km/hr or over and 8% to 55% reductions for any type of crash. These are therefore insufficient alone to discriminate signal from noise in the effect. However in this review, in the absence of randomised controlled trials, the inclusion of only controlled before and after studies went some way towards addressing this, by measuring the effect relative to a control situation, as did the inclusion of interrupted time series studies to examine the longer term effect. This was further strengthened by evaluating how the included studies addressed bias attributable to regression to the mean effect.

Austin Bradford Hill (Hill 1965) proposed a list of criteria for strengthening confidence in inferences about treatment effects. The application of these to this speed camera review indicated that all of the studies met the following criteria;

Temporality - speed camera implementation preceded reductions in speed and crashes.

Consistency all studies, despite different investigations, various times, alternative methodologies, different populations and a variety of geographic settings showed similar results i.e. reductions in speed and crashes.

Theoretical plausibility - the theory that speed camera implementation with associated fines and penalties will result in speed reduction and thus crashes, was a highly plausible explanation.

Coherence - the conclusion 'made sense' given the current knowledge about human behaviour and the control of traffic speeds.

Specificity - with regards to the observed reduction in speed and crash outcomes being specifically due to the introduction of speed cameras, the use of control roads or control sections of road, assisted in ruling out other possible causes.

Strength of effect - the strength of intervention, which was examined using the 95% confidence interval for speed and crash based effects relative to control, was inconclusive. This was due to insufficient reporting and lack of data for calculating confidence intervals in most studies.

Dose-response - no studies specifically looked at dose-response relationships in terms of systematically increasing the number of speed cameras and examining this effect on speed or crashes.

Considered together the studies included in this review met the first 4 and arguably 5 of the 7 criteria listed in the Bradford-Hill guide. The results of this systematic review were consistent across all studies, showing that speed cameras do reduce road traffic crashes, as well as those resulting in road injuries and deaths. Whilst this is an important finding, as the prevention of any road injury or death is desirable, we are unable to deduce the overall magnitude or significance of this effect.

Randomised controlled trials (RCTs) are difficult to conduct in road safety enforcement studies. For instance, speed cameras are most often introduced at sites based on their history of high rates of speed related crashes. In these cases it would be considered unethical to randomise intervention to some traffic 'hot-spots' and not to others, especially when the hypothesis is that the intervention will be beneficial. Instead of camera deployment to high crash locations only, it may be worthwhile expanding location criteria, thereby enabling RCTs to be ethically conducted in areas other than high risk. It has been suggested that to realise the full potential safety benefits of speed cameras, wider deployment is needed, taking into consideration less traumatic crashes, as well as fatal and serious crashes, in selecting locations for new cameras. It is argued that camera deployment on sites with large numbers of less serious crashes, would reduce the number of these crash types and perhaps proactively prevent more serious crashes (GB 30mph Roads Nationwide). This proposed expansion however, may require a paradigm shift in public attitudes to speeding, as currently some resentment towards automated enforcement exists and speeding, despite it being a significant factor in road injuries and deaths, remains socially acceptable.

Countries currently considering introducing speed cameras have a unique opportunity to plan the deployment of speed cameras in such a way that it also provides the basis for solid evidence of their effect on speed and crash outcomes. As a result, well-executed RCTs, using matched pairs of camera locations or clusters of camera locations, as well as quasi-experimental research designs such as, controlled before-after trials (using matched location groups) and additionally interrupted time series studies could be conducted. Furthermore, a lengthy pre-deployment stage would be necessary, with speed and crash data meticulously collected, under pre-specified transparent guidelines and methodology. Collection needs to continue in this way during the intervention period and for a lengthy follow-up period after intervention. However difficult, there is a need for international standardization of data collection methods, including standards on how best to collect and measure speeds and crash data, thus enabling the comparison of studies. A controlled introduction of speed camera enforcement methods is important with careful future planning and anticipated outcomes in mind. In the case of RCTs, a large sampling framework of similarly defined 'lower' risk sites could be ear-marked for randomisation to the intervention and control arms.

The safety benefits of speed camera enforcement (both mobile and fixed cameras) reported in this systematic review are consistent with recent reports elsewhere (Elliott 2005; Wegman 2006) showing consistent reductions in average speeds and proportion of speeding drivers over the speed limits reflected in reductions in all crash types, with more marked effects as expected, in the vicinity of camera sites than in the wider areas. Also consistent with the former reports, reductions for serious injury crashes and fatalities are greater than for all other injury crashes, and effects in urban areas are greater than on rural roads. No sub-group analysis could be performed in this review to compare in any consistent way, the effects of fixed cameras versus mobile cameras because of the considerable heterogeneity alluded to earlier. Whilst the results for studies with a specific focus on time and distance halo effects all showed positive effects, results defied comparison because of the many differences in study periods, number of interventions and methodology.

One of the associated problems with automated speed enforcement is the tendency for some drivers to brake when passing a speed camera and then to speed in excess of the speed limit when out of range of the camera. This behaviour is implicated in some crashes. A relatively new method which has the potential to ameliorate this, is road section control or average speed check. Unlike conventional automated speed systems which measure the speed of a vehicle at one point, section control systems measure the average speeds over a distance from at least 500m to several kilometres. Such a measure can reasonably be expected to have a more sustained positive behavioural effect and perhaps change the culture of speeding over a longer time (Goldenbeld 2005). In the past few years, section control has been introduced in a number of countries and into the United Kingdom and the Netherlands in particular, however, assessment of the unfolding technology and ongoing robust trials are needed to demonstrate the efficacy and effectiveness of this innovation. All studies meeting the criteria for inclusion in this review were conducted in high-income countries. This limits the generalisability of the findings. Middle and low-income countries are gradually introducing speed cameras, however the findings of studies from high-income countries cannot be assumed to apply to these countries. This presents a unique research opportunity for these countries to conduct studies, where the subject of speed cameras is not politicised and yet can be informed by the strengths and weaknesses of the research to date.

Much of road safety research is published in the grey literature. Every possible effort was made to find all relevant controlled trials, however unlike medical databases, which include terms describing the study methodology among its indexing; road safety databases have a very limited range of indexing terms, which made the identification of appropriate studies difficult. A need exists for authors to adequately describe the study design in their reports, and for editors to demand this, so that improvements in thesaurus terms can be made to road safety databases.

Although studies were conducted in varied rural and urban locations, only a few studies reported on the frequency of injurious crashes for different categories of road user (pedestrians, cyclists, motorcyclists, vehicle occupants) therefore not enough data existed to examine the effect of automated enforcement on road trauma by road user category.

The possibility of using speed cameras and associated automated devices in concert with the developing field of Intelligent Speed Adaptation (ISA) systems (Carsten 2002) to further enhance road safety was not within the scope of this current review, but merits further research.

A sizeable body of literature exists which convincingly demonstrates the relationship between relative and absolute excess in speed and road traffic crashes, injuries and deaths. The role for regulating, monitoring, and enforcing speed limitations is not in doubt. The principal problem with traditional enforcement systems is that conventional law enforcement has not been able to keep pace with increased traffic volumes and increased vehicle mileage worldwide (Decina 2007). Aberrant speeding behaviour is widespread and the use of speed cameras and associated automated devices is considered the most efficient way to significantly increase both detection and apprehension rates (Zaal 1994). The main issue then, is establishing that speed camera enforcement reduces road traffic crashes, injuries and deaths, as per the findings in this review. It is speculative whether more intense speed enforcement and higher penalties would be more effective, particularly for more substantial deviations from the posted speed. However, the rationale of using speed cameras to impose safe speeds and limit maximum speeds, for improving road safety is well-founded.

AUTHORS' CONCLUSIONS

Implications for practice

Speed cameras and related automated enforcement devices are a worthwhile interventions for reducing road traffic injuries and deaths in both rural and urban settings. Considering continuing increases in traffic volume worldwide, automated enforcement with speed cameras to curb aberrant speeding behaviour, is a rational intervention to augment or supersede conventional enforcement. Speed cameras used for road section control, which measure average speed over distance, together with related emerging technologies arguably have the potential to favourably influence speeding behaviour and thus enhance road safety.

Implications for research

The results of this systematic review are consistent across studies, showing that speed cameras do reduce road traffic crashes, as well as those resulting in road injuries and deaths. However, in this study, an overall magnitude or significance of this effect could not be deduced because of heterogeneity in background information and road and traffic related factors. An extensive literature exists on issues pertaining to speed cameras. Nonetheless, when searching for studies we found numerous uncontrolled before after studies, many studies without any 'before' data and no randomised controlled trials. For the future, interventions using speed cameras and related automatic speed enforcement devices need to be scientifically evaluated using well designed trials, conducted over sufficient time, with several data collection points and controls where possible. These studies also need to clearly show how potential study bias and confounding is controlled, and use standardised study analyses and outcome methodology, so that their true effectiveness can be more accurately assessed. Ideally, this can be more readily achieved if road safety authorities and academic research entities collaborate in the conduct of automated speed enforcement studies through all phases, from program planning to program completion.

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REFERENCES

References to studies included in this review

AU NSW 1 ***{published data only}***
Armour M. The effect of police presence on urban driving speeds. *Australian Road Research* 1984;**14**(3):142–8.

AU NSW 2 ***{published data only}***
Cairney PT. The effect of aerial enforcement on traffic speeds. Proceedings 14th ARRB Conference, Part 4. 1988: 126–32.
* Kearns IB, Webster KA. The effect of aerial speed enforcement on traffic crashes. Traffic Authority of New South Wales, Research Note RN 4/88 1988:1–12. [: ISSN 0314–9846, ISBN 0–7240–7291–8]

AU NSW 3 ***{published data only}***
ARRB Group Project Team. Evaluation of the fixed digital speed camera program in NSW (RC 2416). Roads and Traffic Authority, NSW Australia May 2005:1–51.

AU QLD 1 ***{published data only}***
Newstead SV, Cameron MH, Leggett LMW. The crash reduction effectiveness of a network-wide traffic police deployment system. *Accident Analysis and Prevention* 2001; **33**(3):393–406.

AU QLD 2 ***{published data only}***
* Newstead SV, Cameron M. Evaluation of the crash effects of the Queensland speed camera program. Monash University Accident Research Centre, Report No. 204 2003:1–35.
Walsh D, Wessling G. Speed Cameras: Queensland last off the blocks but is it leading the race?. 3rd National Conference on Injury Prevention and Control. Brisbane, Queensland, Australia. 1999:79–83.

AU South Australia ***{published data only}***
* Cairney P T, Fackrell H L. The effects of a 40km/h local area speed limit on traffic behaviour and community perceptions and opinion. Australian Road Research Board -Research Report ARR No 243 1993:1–23. [: ISBN 0 86910 600 7, ISSN 0518 –0728]
Cairney PT, Harwood CW. Experience with local area speed limit in Unley, South Australia. Proceedings 17th ARRB Conference, part 5. 1994:323–40.

AU Tasmania ***{published data only}***
Leggett LMW. The effect on accident occurrence of long-term low intensity police enforcement. 14th Australian Road Research Board (ARRB) Conference. 1988; Vol. Part 4:92–104.

AU VIC 1 ***{published data only}***
* Cameron M, Cavallo A, Gilbert A. Crash-based evaluation of speed camera program in Victoria 1990 -1991, Phase 1: General effects. Phase 2: Effects of program mechanisms. Monash University Accident Research Centre (MUARC) Victoria 3800, Australia 1992; Vol. Report No 42:1–76.
Newstead S, Mullan N, Cameron M. Evaluation of the speed camera program in Victoria 1990-1993. Phase 5: Further investigation of localised effects on casualty crash frequency and severity. Monash University Accident Research Centre (MUARC) Victoria 3800, Australia 1995; Vol. Report No 78:1–27.
Rogerson P, Newstead S, Cameron M. Evaluation of the speed camera program in Victoria 1990 -1991, Phase 3: Localised effects on casualty crashes and crash severity, Phase 4: General effects on speed. Monash University Accident

Research Centre (MUARC) Victoria 3800, Australia 1994; Vol. Report No 54:1–41.

AU VIC 2 ***{published data only}***
* Diamantopoulou K, Corben B. The impact of speed camera technology on speed limit compliance in multi-lane tunnels. Road Safety Research, Policing and Education Conference. Adelaide, South Australia. 2002. [: ISBN 1–876346–46–9 ISBN 1–876346–46–9]
Donnelly T. Application of system engineering techniques to optimise benefits of fixed speed cameras. Tenix Solutions Melbourne, Victoria, Australia 2003.

AU VIC 3 ***{published data only}***
* Diamantopoulou K, Cameron M. An evaluation of the effectiveness of overt and covert speed enforcement achieved through mobile radar operations. Report no 187, Monash University Accident Centre (MUARC) March 2002:xiv + 42. [: ISBN 0 7326 1486 x4]
Diamantopoulou K, Cameron M, Shtifelman M. Evaluation of moving mode radar for speed enforcement in Victoria 1995-1997. Monash University Accident Research Centre (MUARC) Victoria, Australia 1998.
Diamantopoulou K, Cameron M, Shtifelman M. The effect of mobile radar devices and associated publicity on road trauma in Victoria. Road Safety Research, Policing and Education Conference. Wellington, New Zealand. 1998.

CA British Columbia ***{published data only}***
Chen G, Wilson J, Meckle W, Cooper P. Evalaution of photo radar program in British Columbia. *Accident Analysis and Prevention* 2000;**32**:517–26.

CA Toronto ***{published data only}***
Hauer E, Ahlin FJ. Speed enforcement and speed choice. *Accident Analysis and Prevention* 1982;**14**(4):267–78.

CA Vancouver B.C. ***{published data only}***
Chen G, Meckle W, Wilson J. Speed and safety effects of photo radar enforcement on a highway corridor in British Columbia. *Accident Analysis and Prevention* 2002;**34**: 129–38.

DE Germany ***{published data only}***
Lamm R, Kloeckner JH. Increase of traffic safety by surveillance of speed limits with automatic radar devices on a dangerous section of a German autobahn: a long term investigation. *Transportation Research Record* 1984;**974**: 8–16.

DK Denmark ***{published data only}***
Agustsson L. Automatic Speed enforcement. The Danish pilot project [Automatisk hastighedskontrol, Rapport 210]. Danish Road Directorate 2001.

ES Barcelona ***{published data only}***
Perez K, Mari-Dell'Olmo M, Borrell C. Reducing road traffic injuries: Effectiveness of speed cameras in an urban setting. *American Journal of Public Health* 2007;**97**(9): 1632–7.

FI Finland ***{published data only}***
Makinen TE. Halo effects of automatic speed enforcement. Technical Research Centre of Finland (VTT) 2001:341–5.

GB 30mph Roads Nationwide ***{published data only}***
* Mountain L, Hirst W, Maher M. Costing lives or saving lives? A detailed evaluation of the impact of speed cameras on safety. *Traffic Engineering and Control* September 2004; **45**(8):280–7.
Mountain L J, Hirst W, Maher M. Are speed enforcement cameras more effective than other speed management measures? The impact of speed management schemes on 30 mph roads. *Accident Analysis and Prevention* 2005;**37**: 742–54.

GB Cambridge ***{published data only}***
* Hess S. An analysis of the effects of speed limit enforcement cameras with differentiation by road type and catchment area. Centre for Transport Studies, Imperial College, London UK (MPhil project) 2003:1–14.
Hess S, Polack J. An analysis of the effects of speed limit enforcement cameras on accident rates. Transportation Research Record, Centre for Transport Studies, Imperial College, London UK 2003:1–16.

GB Nationwide ***{published data only}***
Gains A, Heydecker B, Shrewsbury J, Robertson S. The national safety camera programme -Three-year evaluation report. Department of Transport. Road Safety Division. London UK 2004:1–110.
Gains A, Humble R, Heydecker B, Robertson S. A cost recovery system for speed and red-light cameras - Two year pilot evaluation. Department of Transport. Road Safety Division. London UK 2003; Vol. Version 3:1-1 to J -1.
* Gains A, Nordstrom M, Heydecker B, Shrewsbury J, Mountain L, Maher M. The national safety camera programme: Four year evaluation report. Deparment of Transport. Road Safety Division. London. UK. PA Consulting for Department of Transport. London. U.K. December 2005:1–160.

GB Norfolk ***{published data only}***
Jones AP, Sauerzapf V, Haynes R. The effects of mobile speed camera introduction on road traffic crashes and casualties in a rural county in England. *Journal of Safety Research* 2008;**39**:101–10.

GB South Wales ***{published data only}***
Christie SM, Lyons R A, Dunstan FD, Jones SJ. Are mobile speed cameras effective? A controlled before and after study. *Injury Prevention* 2003;**9**(4):302–6.

GB West London ***{published data only}***
Highways Agency's London Network and Customer Services (LNCS). West London speed camera demonstration project. London Accident Analysis Unit (LAAU), London Research Centre (LRC) 1997:1–45.

HK Hong Kong ***{published data only}***
Hung-Leung C. Speed enforcement camera systems in Hong Kong. HKSAR, Transport Department Hong Kong 2000:386–94.

NL Friesland ***{published data only}***
Goldenbeld C, van Schagen I. The effects of speed enforcement with mobile radar on speed and accidents: An evaluation study on rural roads in the Dutch province

Friesland. *Accident Analysis and Prevention* 2005;**37**: 1135–44.

NL Netherlands ***{published data only}***
Oei HL. Automatic speed management in the Netherlands. *Transportation Research Record* 1996;**1560**:57–64.
* Oei HL, Polak PH. Effect of automatic warning and enforcement on speed and accidents: Results of an evaluation study in four Dutch provinces [Effect van automatische waarschuwing en toezicht op snelheid en ongevallen: Resultaten van een evaluatie–onderzoek in vier Provincies]. Leidschendam, Institute for Road Safety Research SWOV, Netherlands 1992; Vol. R–92–23.

NO Nationwide ***{published data only}***
Elvik R. Effects on accidents of automatic speed enforcement in Norway. *Transportation Research Record 1595* 1997;**1597**: 1–19.

NO Oslo ***{published data only}***
Vaa T. Increased police enforcement: Effects of speed. *Accident Analysis & Prevention* 1997;**29**(3):373–85.

NZ Christchurch ***{published data only}***
Tay R. Do speed cameras improve road safety?. Traffic and transportation studies: International conference on traffic and transportation studies. Beijing, China. July 2000: 44–57.

NZ Nationwide ***{published data only}***
* Keall MD, Povey LJ, Frith WJ. Further Results from a Trial Comparing a Hidden Speed Camera Programme with Visible Camera Operation. *Accident Analysis and Prevention* 2002;**34**(6):773–7.
Keall MD, Povey LJ, Frith WJ. The relative effectiveness of a hidden versus a visible speed camera programme. *Accident Analysis and Prevention* 2001;**33**(2):277–84.

US Arizona 1 ***{published data only}***
Shin K, Washington S P, van Schalkwyk I. Evaluation of the Scottsdale Loop 101 automated speed enforcement demonstration program. *Accident Analysis and Prevention* 2009;**41**:393–403.

US Arizona 2 ***{published data only}***
Retting RA, Kyrychenko SY, McCartt AT. Evaluation of automated speed enforcement on Loop 101 freeway in Scottsdale Arizona. *Accident Analysis and Prevention* 2008; **40**:1506–12.

US Maryland ***{published data only}***
Retting RA, Farmer CM, McCartt AT. Evaluation of automated speed enforcement in Montgomery County, Maryland. Insurance Institute for Highway Safety January 2008:1–10.

US North Carolina ***{published data only}***
* Cunningham CM, Hummer JE, Moon J-P. An Evaluation of the Safety Effects of Speed Enforcement Cameras in Charlotte, NC. Final Report. Presented to the North Carolina Governors Highway Safety Program. Institution for Transport Research and Education. North Carolina State University, Raleigh, North Carolina October 2005: 1–156.

US Washington DC ***{published data only}***
Retting RA, Farmer CM. Evaluation of speed camera enforcement in the District of Columbia. Transportation Research Record 1830 2003, issue 03–4012:34–7.

References to studies excluded from this review

Al Maseid 1997 ***{published data only}***
Al Maseid HR. Effect of police enforcement on drivers behaviour. VTI Conference: Traffic Dafety on two Continents, Lisbon, Portugal. Sept 22–24,1997; Vol. 9A, Part 8:37–58.

Ali 1997 ***{published data only}***
Ali SY, Al-Saleh O, Koushki PA. Effectiveness of automated speed monitoring cameras in Kuwait. *Transportation Research Record* 1997;**1595**:20–6.

Bellotti 2001 ***{published data only}***
Bellotti P. Gloucester safer city project. Department of Transport UK TRL - Dumas work package 9 2001.

Benekohal 1993 ***{published data only}***
Benekohal RF, Resende PTV, Zhao W. Temporal speed reduction effects of drone radar in work zones. *Transportation Research Record* 1993;**1409**:32–41.

Bourne 1993 ***{published data only}***
Bourne M, Cooke R. Victoria's speed camera program. *Crime Prevention Studies* 1993;**1**:177–92.

Brimson 2002 ***{published data only}***
Brimson T, Anderson R. Fixed red light and speed cameras in Canberra: Evaluating a new digital technology. RS2002 Conference. Canberra, ACT, Australia, 2002:401–9. [: ISBN 1–876346–46–9]

Cameron 2003 ***{published data only}***
Cameron M, Newstead S, Diamantopolou K, Oxley P. The interaction between spped camera enforcement and speed-related mass media publicity in Victoria. Monash University Accident Research Centre (MUARC), Victoria, Australia 2003, issue Report 201.

Casey 1993 ***{published data only}***
Casey SM, Lund AK. The effects of mobile roadside speedometers on traffic speeds. *Accident Analysis and Prevention* 1993;**25**(5):627–34.

Champness 2005 ***{published data only}***
Champness P, Sheehan M, Folkman L-M. Time and distance halo effects of an overtly deployed mobile speed camera. http://eprints.qut.edu.au/archive/00003952. Brisbane: QUT ePrints, 2005:1–10.

Chin 1999 ***{published data only}***
Chin HC. An investigation into the effectiveness of the speed camera. Proceedings of the Institution of Civil Engineers Transportation. Journals Dept, Thomas Telford Ltd, Thomas Telford House, 1 Heron Quay, London E14 4JD, 1999; Vol. 135:93–101. [: Paper 11733]

Diamantopoulou 1998 ***{published data only}***
Diamantopoulou K, Cameron M, Shtifelman M. The effect of mobile radar devices and associated publicity on

road trauma in Victoria. Road Safety Research, Policing, Education Conference. Wellington, New Zealand. 1998.

Gunarta 2005 ***{published data only}***
Gunarta S, Kerr G. Speed impacts of mobile speed cameras in Christchurch. *Road and Transport Research* June 2005;**14**(2):16–27.

Ha 2003 ***{published data only}***
HA TJ, Kang JG, Park JJ. The effects of automated speed enforcement systems on traffic flow: Characteristics and accidents in Korea. *Institute of Transportation Engineers ITE journal* 2003;**73**:28–31.

Hakkert 2000 ***{published data only}***
Hakkert AS, Gitelman V, Cohen A, Doveh E, Umansky T. The evaluation of effects on driver behavior and accidents of concentrated general enforcement on interurban roads in Israel. *Accident Analysis and Prevention* 2001;**33**:43–63.

Hirst 2005a ***{published data only}***
Hirst WM, Mountain LJ, Maher MJ. Are speed enforcement cameras more effective than other speed management measures? An evaluation of the relationship between speed and accident reductions. *Accident Analysis and Prevention* 2005;**37**:731–41.

Hirst 2005b ***{published data only}***
Hirst WM, Mountain LJ, Maher MJ. Are speed enforcement cameras more effective than other speed management measures? The impact of speed management schemes on 30 mph roads. *Accident Analysis and Prevention* 2005;**37**:742–54.

Holland 1996 ***{published data only}***
Holland CA, Connor MT. Exceeding the speed limit: An evaluation of the effectiveness of a police intervention. *Accident Analysis and Prevention* 1996;**28**(5):587–97.

Hook 1995 ***{published data only}***
Hook D, Kirkwood A, Evans D. Speed cameras in Oxfordshire. *Highways and Transportation* 1995;**42**(2):11–3.

Hooke 1996 ***{published data only}***
Hooke A, Knox J, Portas D. Cost benefit analysis of traffic light and speed cameras. Police Research Group. London 1996, issue Police Research Series Paper 20:1–58.

Johannessen 2002 ***{published data only}***
Johannessen S. New strategies and methods for speed management in Norway. 15th ICTCT Conference, Brno, Republic of Czechoslovakia. Oct 24–25, 2002:1–12.

Lund 1977 ***{published data only}***
Lund HV, Brodersen F, Jorgensen NO. A study of the effects of police enforcement on driver behaviour [Radet for Trafiksikkerhedsforskning: Trafikantadfaerd under skaerpet politiovervagning Rapport 19, Kovenhavn]. Copenhagen, Denmark 1977:7–98. [: ISBN 87–7327–005–9]

Mackie 2003 ***{published data only}***
Mackie A, Wells P. Gloucester safer city: Final report. Road Safety Division, Department of Transport 2003, issue TRL Report 589:1–65.

Mara 1996 ***{published data only}***
Mara MK, Davies RB, Frith WJ. Evaluation of the effect of compulsory breath testing and speed cameras in New Zealand. Combined 18th ARRB Transport Research Conference. Sept 2–6, 1996:Part 5, 269-82.

Oei 1995 ***{published data only}***
Oei H, Goldenbeld C. Evaluation of the enforcement of speed on 80 km/h and 100 km/h roads in the province of Friesland [Evaluatie van het toezicht op snelheid op 80 –en 100 km/uur–wegen in Friesland]. Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV 1995, issue R–95–24:3–59.

Oregon 1997 ***{published data only}***
Cities of Beaverton, Portland. Oregon. Photo radar demonstration project. http://www.portlandonline.com/ 1997:1–12.

Pigman 1989 ***{published data only}***
Pigman JG, Agent KR, Deacon JA, Kryscio RJ. Evaluation of unmanned radar installations. *Transportation Research Record* 1989;**1244**:7–16.

Povey 2003 ***{published data only}***
Povey LJ, Frith WJ, Keall MD. An investigation of the relationship between speed enforcement, vehicles speeds and injury crashes in New Zealand. Road Safety Research, Policing and Education Conference. Land Transport Safety Authority, New Zealand. 2003:1–11.

Rooijers 1991 ***{published data only}***
Rooijers AJ, De Bruin RA. Selective enforcement of speeding behaviour in built-up areas. Institute for Road Safety Research SWOV, Netherlands 1991, issue C 229: 51–4.

Sisiopiku ***{published data only}***
Sisiopiku VP, Patel H. Study of the impact of police enforcement on motorists' speeds. *Transportation Research Board* 1999;**1693**:31–6. [: ISBN 0309071178,ISSN 03611981, Project no 1693 –007]

Stradling 2002 ***{published data only}***
Stradling S, Campbell M. The effects of safety cameras on drivers. RoSPA: 67th Road Safety Congress 'Safer Driving - The Road to Success'. 4–6th March 2002:1–11.

Swali 1993 ***{published data only}***
Swali L. The effect of speed cameras in West London. Traffic management and road safety, PTRC seminar, Manchester. PTRC Education and Research Services Ltd, 1993.

Teed 1993 ***{published data only}***
Teed N, Lund AK. The effect of laser speed-measuring devices on speed limit law enforcement in Charleston, South Carolina. *Accident Analysis and Prevention* 1993;**25**(4):459–63.

Werner 2002 ***{published data only}***
Werner J. Dutch variable speed pilot test employs photo speed enforcement. ITS Cooperative Deployment Network. National Associations working group for ITS, 2002:1–2. [: 00934671]

Woo 2007 *{published data only}*
Woo TH, Shih-Ming Ho, Hung-Lin Chen. Monitoring Displays coupled with Speed Cameras: Effectiveness on speed reduction. *Transportation Research Record: Journal of the Transportation Research Board* 2007;**7**:30–6.

Additional references

Aarts 2006
Aarts L, van Schagen I. Driving speed and the risk of road crashes: A review. *Accident Analysis and Prevention* 2006;**38**: 215–24.

Aeron-Thomas 2005
Aeron-Thomas A, Hess S. Red light cameras for the prevention of road traffic crashes. *Cochrane Database of Systematic Reviews* 2005, Issue 2. [DOI: 10.1002/14651858.CD003862.pub2]

ATSB 2003
Australian Transport Safety Bureau. Database Statistics. Requested from the ATSB database 2003.

Carsten 2002
Carsten O. European Research on ISA: Where are we now and what remains to be done. Proceedings: ICTCT workshop Nagoya, Japan. 2002:1–14.

Chen 2000
Chen G, Wilson J, Meckle W, Cooper P. Evaluation of photo radar program in British Columbia. *Accident Analysis and Prevention* 2000;**32**:517–26.

Connelly 2006
Connelly LB, Supangan R. The economic costs of road traffic crashes: Australia states and territories. *Accident Analysis and Prevention* 2006;**38**:1087–93.

Decina 2007
Decina LE, Thomas L, Srinivasan R. Automated enforcement: A compendium of worldwide evaluations of results. Office of Research and Technology, National Highway Traffic Safety Administration (NHTSA) Washington DC 20590 September 2007, issue DOT HS 810 763.

Elliott 2005
Elliott M, Broughton J. How methods and levels of policing affect road casualty rates. Transport Research Laboratory (TRL) Workingham 2005; Vol. Report TRL 637.

Elvik 2000
Elvik R. How much do road accidents cost the national economy?. *Accident Analysis and Prevention* 2000;**32**(6): 849–51.

EPOC
Cochrane Effective Practice and Organisation of Care Review Group (EPOC). The Data Collection Checklist. EPOC, Institute of Population Health, University of Ottawa, 1 Stewert St, Ottawa,Ontario, Canada K1N 6N5 http://www.epoc.uottawa.ca.

Glasziou 2007
Glasziou P, Chalmers I, Rawlins M, McCulloch P. When are randomised trials unnecessary? Picking signal from noise. *BMJ* 2007;**334**:349–51.

Goldenbeld 2005
Godenbeld Ch, Schagen Inlg van. The effects of speed enforcement with mobile radar on speed and accidents: An evaluation study on rural roads in the Dutch province of Friesland. *Accident Analysis and Prevention* 2005;**37**: 1135–44.

Hauer 1997
Hauer E. Observational Before-After Studies in Road Safety. Pergamon. Oxford 1997.

Hauer 2002
Hauer E, Harwood DW, Council FM, Griffith MS. Estimating safety by the Empirical Bayes method. Transportation Research Record 2002, issue 1784:126–31.

Hill 1965
Hill AB. The environment and disease: association or causation?. *Proceedings of the Royal Society of Medicine* 1965; **58**:295–300.

Jacobs G 2000
Jacobs G, Aeron-Thomas A, Astrop A. Estimating global road fatalities. Transport Research Laboratory (TRL), Crowthorne, United Kingdom. 2000; Vol. Report No 455.

Keall 2001
Keall MD, Povey LJ, Frith WJ. The relative effectiveness of a hidden versus a visible speed camera programme. *Accident Analysis and Prevention* 2001;**33**:277–84.

Krug 2002
Krug E (Ed). Injury a leading cause of the global burden of disease. Geneva, World Health Organisation (WHO) 2002.

Murray 1997
Murray CJL, Lopez AD. Alternative projections of mortality and disability by cause 1990-2020: Global burden of disease study. *Lancet* 1997;**349**:1498–504.

Peden 2004
Peden M, Scurfield R, Sleet D, Mohan D, et al (Eds). World report on road traffic injury prevention. Geneva, World Health Organisation (WHO) 2004.

Pilkington 2002
Pilkington P. Increasing visibility of speed cameras might increase deaths and injuries on roads. *BMJ* 2002;**324**:1153.

Pilkington 2005
Pilkington P, Kinra S. Effectiveness of speed cameras in preventing road traffic collisions and related casualties: systematic review. *BMJ* 2005;**330**:331–4.

U.S. Department of Transportation 2004
U.S. Department of Transportation. Traffic Safety Facts, 2004 Data:Speeding (DOT HS 809915). National Center for Statisitcs and Analysis, National Highway Traffic Safety Administration (NTHSA) Washington DC 20590 2004: 1–6.

US TRB 1998
Transportation Research Board. Managing Speed: Review of current practice for setting and enforcing speed limits. Special report 254. http://gulliver.trb.org/publications/sr/sr254.pdf 1998; Vol. Washington DC.

Wegman 2006
Wegman F, Goldenbeld C. Speed management: Enforcement and new technologies. SWOV Institute for Road Safety Research, Leidschendam, The Netherlands 2006, issue R–2006–5:1–29.

Zaal 1994
Zaal D. Traffic law enforcement: A Review of the Literature. Monash Accident Research Centre (MUARC) Victoria, Australia 1994; Vol. Report No 53:1–200.

* *Indicates the major publication for the study*

CHARACTERISTICS OF STUDIES

Characteristics of included studies *[ordered by study ID]*

AU NSW 1

Methods	Controlled before-after study. Study period from February 1982 for nine weeks. Speed measurement before, during and after enforcement. Two experimental and one control site.
Participants	Eastern suburbs of Sydney, two lane sub-arterials carrying less than 10,000 vehicles/day but carrying commuter traffic. Streets had 60 km/h speed limits
Interventions	Police presence in stationary car with radar units at both sites, overt at site 1 and hidden from view at the primary 2nd site. Primary point for speed measurement was 300m post police car and secondary point was 200m before police car, at both sites. Enforcement periods were 8.00am to 9.00am and 2.00pm to 3.00pm. Speed surveys were conducted between 8.00am to 9.30am and 2.00pm to 3.30pm, i.e. for 30 minutes after police had left the site
Outcomes	Effects of enforcement on traffic speeds on urban roads including halo effects. The main finding showed the proportion of vehicles exceeding the speed limit reduced by about 70% when police were present and a time halo effect on commuter traffic lasted at least two days
Notes	Perception of enforcement only. Outcomes measured - proportions of speeders over 60 km/h and 70 km/h. Control site characteristics - also had a 60 km/h limit and located in the eastern suburbs. No other 'control' characteristics described and authors didn't describe any other possible confounders

AU NSW 2

Methods	Controlled before-after study. 'Before' crash data January 1985 to November 1986. 'After' crash data January to November 1987. Only 100 km/h speed limit areas within sites used for crash data. Study period for speed data, December 1986 to March 1987. Speed data points - before and again at three and six weeks after start of aerial enforcement. Two sites were chosen for detailed examination. Speed was measured at four locations (upstream and downstream as well as within marked area) for each site on four days - one day before aerial enforcement, during, one day after and on the fourth day after operation started. 14 experimental and 14 control sites used for crash analyses and 10 experimental and 5 control sites used for speed analyses
Participants	This study reports an investigation of crashes at nine of 24 rural highway sites in New South Wales that came into operation in December 1986. The nine experimental grids provided 14 experimental sites which were matched by 14 control sites. For speed, 10 experimental sites were chosen and five matched control sites were selected. All sites were within a 100 km/h speed limit zones except for two experimental sites and one control site, which were in 110 km/h zones

AU NSW 2 *(Continued)*

Interventions	Aerial surveillance involving a police aircraft flying at 500 to 700m over a series of marked grids on roadways. Speeds were calculated by an observer using a stopwatch and radar unit who timed vehicles over set distances and radioed 'speeder information' to ground crew police in hidden patrol car who then issued speeders with traffic infringement notices
Outcomes	Reports crash and speed outcomes. The main finding was a 23% reduction in crashes at experimental sites during the day and a 21% reduction at other times, relative to trends in crashes at control sites. Reduction in overall mean speed was a small 2-3 km/h. Similar reductions were found at controls sites. While aerial surveillance was operating, speed reductions extending up to 14 km's downstream from the marked zone was evident and some reduction was evident for the day after
Notes	Experimental (E) and control (C) sites were matched in terms of suitability for aerial surveillance, on average annual daily traffic (E sites averaged 7,200 vehicles per day while C sites averaged 8,000), length (E sites averaged 14.3 km while C sites averaged 16.6 km), road classification (all sites were 2 or 3 lane rural highways) and speed limit (all had a predominant 100 km/h limit). The possibility of regression to mean regarding the number of crashes at experimental versus control site was discussed. When comparing both crash and speed outcomes, the speed effects were small, however, the speed study was conducted over a short six week period whilst it was noted from the 'crash study' findings, that crash effects were only evident after the program had been in operation a few months

AU NSW 3

Methods	Controlled before-after study with a 3 year period of 'before data' collection and a 2 year period of 'after' data. The overall length of the study was not given
Participants	Initially, 20 overt fixed camera sites increasing to 28 sites over the course of the study with a total 81 cameras in use. These sites were located in both urban and rural areas and all displayed prominent warning signs
Interventions	Crash data were collected from the 28 camera sites which were defined as the 'camera length' ; the black length section of road in which the camera was located (1 to 3.3 km in length). Data were also collected for upstream and downstream adjacent sections each typically 1 -2 km's in length. Speed data were collected from 20 of these sites. Camera sites were matched with 33 controls based on speed limits, number of lanes and types of roads
Outcomes	The main outcomes at 1 year post showed a 6.3 km/h reduction in mean speeds at cameras sites. At 2 years this reduction was 5.8km/h. For percentage exceeding the speed limit, the reduction was 70% at camera lengths at 1 year and this reduction was maintained at 2 years. There were significant reductions of 86% and 88% along camera lengths at 1 and 2 year's for percentage exceeding speed limits by at least 10 km/h For the aggregate changes in crashes, there was a significant 22.8% reduction in all fatal plus injurious crashes at the camera section, a 20.1% significant reduction in injury crashes along the camera lengths and an 89.8% significant reduction in fatal crashes along the camera lengths of road during the 2 years post implementation
Notes	Sites with high crash numbers were selected for treatment however, no consideration was given to the possibility of biased results due to possible RTM effects. Likewise, no data on control sites were provided in the report and no account was given or adjustment made for other possible confounders.There appeared to be an assumption that traffic volumes remained similar for both experimental and control sites for the whole study period. The study reports increases in speed and crashes at some adjacent non-enforced sites over a 2 year period, which may indicate crash migration occurred

AU QLD 1

Methods	Quasi-experimental with comparison group, using trend analysis. Study period 1986 to 1996. Experimental sites have been compared to sites not influenced by the enforcement program. 'Before' data from 1986. Progressive introduction of enforcement program from 1992. 'After' data to end of June 1996
Participants	Statewide Queensland. State stratified into seven police regions each of which is further divided into urban and rural areas (making 14 strata in total). These areas are further divided into police districts that cover groups of police divisions. Each individual police division (279 police divisions by close of study) select a road segment, typically with 40 sites within it, for enforcement. Speed zones were defined as greater than 60 km/h and zones equal or less than 60 km/h
Interventions	Stationary marked police car at a randomly selected site for two hours of enforcement between 6.00am and midnight
Outcomes	Effects of program on crash frequency and crash severity in Queensland (four crash severity levels) Crash data from five years before intervention. All other outcome data come from: 1. crashes enforced time in enforced area 2. crashes un-enforced time in enforced area 3. crashes enforced time in un-enforced area 4. crashes un-enforced time in un-enforced area Estimated 31% reduction in fatal crashes. Overall a significant 11% reduction in total crashes outside of metropolitan Brisbane
Notes	This study of Random Road Watch (RRW) is a traffic policing program in operation in Queensland, Australia. It differs from other road safety enforcement programs in that an explicit resource management technique is used which randomly schedules low levels of police enforcement with the intention of providing long-term widespread coverage of a road network. Outcome crash data from police records rather than an automated system. Characteristics of comparison sites given.

AU QLD 2

Methods	Controlled before-after study. Study conducted from May 1997 to end of June 2001. 'Before' data from January 1992 to December 1996. Experimental areas within 6km of camera site dissected by three (0 to <2km, 2 to <4 km, 4 to <6km). Matched control areas outside the 6 km "zones of influence". Crash data from January 1992 to June 2001.
Participants	Sites throughout Queensland that had undergone a speed limit review and had a high speed related injurious crash history. 500 sites in 1997 to over 2,500 sites by June 2001.
Interventions	Mobile overt cameras used which were randomly deployed and operated for up to six hours per day at one or more of three sites per day
Outcomes	Localised crash effects were measured. Greatest reductions in injury and fatal crashes within 2 km of cameras. A 45% reduction in fatal crashes in areas within 2 km of camera sites. Corresponding reductions of 31%, 39%, 19% and 21% were estimated for hospitalisation, medically treated, other injury and non-injury crashes respectively. This

	equates to an annual crash reduction of 110 fatal, 1100 hospitalisation, 2200 medically treated, 500 other injury and 1600 non-injury crashes in Queensland. For the total post intervention period between January 1997 and June 2001, the aggregate changes in crashes was a significant reduction of 17.5 % in all severity crashes within 2 km of cameras, a 11.4 % reduction in all severity crashes in the 2-4 km zones and a 10.7 % reduction in the 4 to 6 km zone. Significant reductions in no injury crashes were also recorded at 2 to 4 km and 4 to 6 km zones
Notes	Control sites matched by level of urbanisation, similarity of police region and similarity of Random Road Watch (RRW) program. A study limitation was the observation that, crash to nearest camera site didn't necessarily mean that a camera was there at the time. Adjustment was not considered for possible regression to the mean effects

AU South Australia

Methods	Controlled before-after study. Study conducted from November 1991 to February 1993. 'Before' speed data (two data points) from November 1991 to end of February 1991. 'After' speed data (measurement x 4) from March 1992 to February 1993. Ten experimental sites and two control sites.
Participants	Residential area with ten deployment sites (streets) in city of Unley, South Australia approximately 4km from north to south and 700m from east to west
Interventions	Overt mobile speed camera, random deployment to enforce a new 40 km speed limit to local residential streets. Low intensity enforcement. (1.5 hours per fortnight) began March 1992. High intensity enforcement began October 1992 (at least 1.5 hours x 5 per fortnight). Operational conditions for control sites not clearly described
Outcomes	Median traffic speeds reduced sharply by 5 km/h on experimental roads after program launch and reduced very little thereafter despite intensified enforcement, however improvement sustained over the whole trial period whereas control sites showed no change or slight increases in speed
Notes	Controls were matched on the basis of width, length and traffic flow. Assumption that speed limit same for experimental and control streets as they were adjacent. Speed data on all vehicles passing each study site (experimental and control) was collected for one full week during each survey. Both speed and traffic volumes were recorded using Golden river classifiers with amphometer tubes as sensors. This equipment was capable of storing a complete week's data, it achieved this by 'binning' data i.e. instead of recording each vehicle's speed, it simply recorded the passage of a vehicle in a particular speed category which imposed some restrictions on data analysis

AU Tasmania

Methods	Controlled before-after study. Total study length was two years between December 1984 and December 1986. Continuous speed measurement for periods of three days to two weeks in one month in 1984, 1985, 1986. Crash data from 1979 to 1986. Three experimental sites and one control site plus all other Tasmanian roads also used for crash comparisons
Participants	Three road locations each 12 km to 16km in length divided into approximately 1km sections. Road type - contiguous sections of rural highway or main road where speed limit was 110km/h. Control was similar road within 10km of experimental sites
Interventions	Overt stationary police vehicles for 4 by 2 hours periods 7 days per week, random scheduling of road sections, 5 site visits per week for 2 weeks then 2 to 3 site visits thereafter
Outcomes	A significant decrease in mean speeds by average of 3.6 km/h (p=0.01) compared to before, but reduction only maintained during enforcement showing no time halo effect. A significant 58% reduction in serious injury crashes (admitted to hospital or fatal) compared to previous crash history and crash occurrence on other rural roads. In non-enforced times of day a 33% increase in major injury crashes was seen
Notes	Characteristics of trial site lead it to be classified 90 km/h, whilst control site was 110km/h, thus lower mean speeds at trial site. This was taken into account in the analysis and discussion

AU VIC 1

Methods	Interrupted time series design with a control arm for phase 1 and phase 2 of a 5-phase study. Total study period 1983 to 1993.
Participants	Statewide Victoria inclusive of rural and metropolitan areas. Metropolitan areas defined as those areas within specified police districts
Interventions	Interventions were: 1. mobile radar devices 2. hand held laser speed detector devices 3. speed cameras - progressive introduction of 54 speed cameras between December 1989 to January 1991 with 4 distinct points (T1a,T1b, T2a, T2b). Initially speed cameras were overt then from 1990, largely covert.
Outcomes	Phase 1 - General effects; effect of speed camera program on crash rate and severity covering first 12 month post intervention period, December 1989 to December 1990. Phase 2 - Impact of program mechanisms i.e. number of traffic infringement notices (TINs), hours of speed camera operations, amount of paid TV publicity, demerit points in relation to injury crash incidence and severity during low alcohol times of the week across the first two year post intervention period. Phase 3 - Areas and times of operation of speed camera program affecting frequency and severity of all types of injury crashes during both high and low alcohol hours in Melbourne covering 18 months of program (July 1, 1990 to December 31, 1991). Phase 4 - Program effects on speeds, including influence of publicity from sample sites between November 1989 to June 1991 (five measurements) and from continuous sites November 1989 to January 1992 (monthly measurements for one week duration). Phase 5 - builds on phase 3 by analysing localised effects of program in; a) rural towns and rural highways B)

	metropolitan Melbourne. this phase covers an additional 24 months of program (July 1990 to December 1993). Phase 1 and 3 - Injury crash frequency reduced by about 30% on 60km/h Melbourne city, A reduction of about 20% in rural 60km/h zones and a reduction of 14% in rural 100km/h zones. Results from phase 1 and 2 are reported in Table 3, in the additional tables section. Phase 3, 4 and 5, of this 5-phase study did not have before-after data, hence only phase 1and 2 are tabled
Notes	Only results from phase 1 and 2 of this 5-phase study were reported and tabulated, as phases 3, 4 and 5 did not have before and after data. Control area for phase 1 and 2 was another State, New South Wales, as no suitable control in the State of Victoria, thus some limitations, however most comparable in terms of urbanisation, economic activity, population size, vehicle kilometres travelled and unemployment rate. Controlled for random breath test (RBT) program in operation, by restricting relevant crash analysis to low alcohol hours

AU VIC 2

Methods	Controlled before-after study. Study period May 2000 to October 2000, a period of about 20 weeks. 'Before' period 8th May 2000 to 21st May 2000. 'After' period 18th October to 31st October 2000. 1 experimental and 1 control site.
Participants	Domain tunnel Melbourne, three-lane urban road with 80 km/h speed limit. The control was a second three-lane road upstream of the tunnel
Interventions	Fixed position speed camera operating continuously.
Outcomes	Net 3.4% speed reduction (after consideration of changes in average speeds that occurred at control site during the same before-after periods). The proportion of drivers exceeding the 80km/h posted speed limit decreased by a net 66%. For drivers speeding over 90km/h, a net 79% reduction was seen, and for those over 110km/h, a net 76% reduction was reported. Estimated 13% reduction in fatal crashes, 10% reduction in serious injury and 7% reduction in overall injuries
Notes	The 'before' period is when the cameras are in the tunnel but no infringement notices are being issued, therefore arguably not truly independent as not everyone would know the cameras weren't operational. This would probably have the effect of slowing down speed in the before period making differences smaller

AU VIC 3

Methods	Controlled before-after study. Study period 1992 to 1997. 'Before' crash data July 1992 to June 1994. 'After' crash data July 1995 to June 1997. Experimental sites were undivided roads in 100km/h speed zones. Control sites were defined as undivided roads in 100km/h speed zones when mobile radar was not present within four days prior to a crash
Participants	Mainly rural Victoria with some enforcement (about 10% of total mobile enforcement activity) in the outer Melbourne police districts of Victoria

Interventions	Interventions were overt patrol cars using mobile radar, covert patrol cars using mobile radar, and mixed overt/covert cars using mobile radar. Most operations were overt. Intervention events were divided into Period A (July 1995 to June 1996) when 48 radars were in operation and Period B (July 1996 to June 1997) when 73 radars were in operation and Period A+B (July 1995 to June 1997) when up to 73 radars were in operation
Outcomes	Outcomes were reductions in injury crashes within four days of camera enforcement and during July 1995 to July 1997. A net reduction of 71.3% (P=0.064) was found for injury crashes occurring on the same day or up to four days after the enforcement was present. The effect was strongest (a net 73.9% reduction (P=0.045)) on the day when a mix of overt/covert enforcement was in use
Notes	The study compared crashes that occurred during the period of mobile radar enforcement with the period when there was no mobile radar enforcement, however the authors state that other types of enforcement e.g. hand held radars may have been operating on the same roads during the pre-period that may not have been accounted for by changes in the control crashes. Calculation of net percentage change between control and experimental groups was designed to control for other confounders. The analysis assumed that crashes were exclusively influenced by the most recent mobile radar enforcement present in a particular region. This most recent enforcement was considered to override any enforcement that occurred one to four days earlier, which also may have influenced crash rate. Given that a four day residual effect on crashes was found in the analysis, the study authors acknowledge the most recent enforcement may not necessarily have been the most important in influencing crash frequency

CA British Columbia

Methods	Controlled before-after study. Study period January 1991 to July 1997. 'Before' speed data September 1995 to February 1996. 'After' speed data August 1996 to November 1996 at monitoring sites, and from August 1996 to July 1997 at photo deployment sites. 'Before' crash data from January 1991 to February 1996 and 'after' crash data, August 1996 to July 1997
Participants	Province-wide throughout British Columbia. Controls consisted of 19 sites on selected highways and streets where radar was not operating. Data was collected by induction loops from these sites between September 1995 and November 1996. Eight days of speed data collected every month.
Interventions	30 mobile speed cameras using unmarked mini-vans. 30,000 hours of operation recorded in first year with about 250,000 tickets issued. Intervention period was August 1996 to July 1997.
Outcomes	Proportion of speeding vehicles in May 1996 (before) at photo radar sites was 66%. By July 1997(after) it was about 35%. At control sites speeding vehicles in September 1995 was ~73%. In Nov 1996 it was ~61%. Approximately 25% reduction in crashes to that expected. A significant 11% reduction in number of victims with an average decrease of 139 daytime traffic crashes requiring an ambulance. A 17% reduction in daytime crash fatalities.
Notes	Selection criteria for control sites included distance to traffic control devices, non-congestion, speed limits but how well they matched experimental sites not discussed. Controlled for vehicle miles travelled (motor fuel sales) state of the economy (unemployment rate) and amount of

	drink driving (draught beer sales) in modelling. Later beer sales and unemployment rate excluded from time series models. As the total number of speed related crashes were the main focus of this study for the whole of the province, regression to the mean is an unlikely confounder as are spill-over effects

CA Toronto

Methods	Controlled before-after study. Study period October 1979 to December 1979; five week study. Data collection by 2.5 hours per day on weekdays over the five consecutive weeks at four experimental and four control sites
Participants	Locations were semi-rural, two-lane roads west of metropolitan Toronto
Interventions	Four experiments are described, each experiment consisted of measuring speed of vehicles before, during and after enforcement took place. The four experiments differed in the number of days of enforcement. Each of the four experimental sites had an 'upstream' enforcement and a 'downstream' measurement site (latter was 1 to 2.5km from the site of enforcement). In experiment 1 the police van was visible in advance. In experiment 2 to 4 the police vehicle was visible to the driver only 200m to 300m before passing the speed sensors
Outcomes	For a single application of enforcement a 'time halo' lasted for up to three days. When enforcement was applied for five consecutive days, a time halo of at least six days from the last day of enforcement was found. When enforcement was in place the average speed of the traffic stream was reduced at the site of enforcement, upstream and downstream of it. At the site of speed limit enforcement, the average speed of the traffic stream was around the posted speed limit. This reduction in average speed decays exponentially with distance downstream
Notes	Study authors state control sites were selected to take "account of the effect of weather, day of week and other factors". They also state concurrent measurements were done on control roads, otherwise no further description of control characteristics were given or how close control sites were to experiment sites. Little information only on 'before' data.

CA Vancouver B.C.

Methods	Controlled before-after study. Study period August 1995 to March 1998. Introduction of photo radar program April 1996. Enforcement phase started August 2nd 1996. Speed data from August 1995 to April 1998. Two years 'before' crash data from April 1994 to March 1996. Two years 'after' data from April 1996 to March 1998.
Participants	One 22km four-lane highway corridor in rural/semi-rural countryside in province of British Columbia. Controls consisted of other selected highways and streets where radar was not operating, used for crash comparisons. No true control for speed (see notes)

Interventions	12 individual photo radar locations along corridor (not active at the same time). Study corridor was divided into photo-radar influence (PRP) locations and non-photo radar influence (non-PRP) locations. A PRP location was designated as a 2km section of highway, 1 km in each direction from the photo radar enforcement. The non-PRP locations varied in length from 0.4 to 5.9km, depending on the proximity to the adjacent treatment locations
Outcomes	2.8km/h reduction in mean speed at monitoring site 2km from treatment area. A 14% (+/-11%) reduction in expected crashes at PRP locations, a 19% (+/-10%) reduction at non-PRP locations and a 16% (+/-7%) reduction along the study corridor as a whole
Notes	Site specific study using data from the same period as the province wide study. PRP and non PRP areas cannot be considered independent of each other as in some cases the non -influence areas only 400m long and are in between PRP areas. Results suggest this lack of independence too. Speed data was captured at PRP locations by the photo radar device but only when radar operating. Speed captured at the monitoring site (2km south of the nearest photo radar) on a 24 hour basis collected over an 8-day period every month by induction loop for both the before and after period. Controlled for regression to mean

DE Germany

Methods	Controlled before-after study. 12 year total study period 1970 to 1983. Two 'before' speed measurements in 1971 and 1972. In May 1973 radar installed . Eight 'after' speed measurements between 1974 and 1983. 12 years 'before' crash data and 9 years 'after' data, between 1960 and 1982
Participants	One interstate road (A3) on the autobahn at Elzer mountain in Germany. The rest of the same autobahn used as the comparison. Speed limits of 100km/h for car lanes and 40km/h for truck lane
Interventions	Overt speed cameras by three in fixed position on bridges (corresponding to three lanes on autobahn) operating continuously. Police surveillance also in operation several times per year. Speed limits of 100km/hr for cars and 40km/hr for trucks.
Outcomes	In 1971 before enforcement the median speed was 137km/h and 122km /h in the left and middle car lane. By 1981 the median speed was 97km/h and 94km/h in these lanes. The 85th percentile speed reduced from 150km/h and 135km/h in the left and middle lanes in 1971 to 108km/h and 98 km/h respectively by 1981. Reductions in median and 85th percentile speed also occurred in the truck lane, with median speed down from 55km/h to 32km/h between 1971 and 1981 and 85th percentile speed down from 80km/h to 41km/h in the same timeframe. Personal injury crash frequency reduced by a ratio of 18:1 between 1971 and 1981. Reduction in crashes from 200 in 1970-1971 to 84 in 1973 to about 27 in 1980 for the most dangerous downgrade section. Fatalities reduced from eight in 1970 to 1971 to three in 1973 to an average of one per year since 1976. Personal injury crashes reduced from about 82 per year in 1970 to 1971 to 27 in 1973 to about seven per year since 1976
Notes	Speed measures in the before period relate to speeds before a) introduction of speed limits and b) introduction of speed cameras. Summary statistics not given. Not clear if the analyses controlled for any known or potential confounders

DK Denmark

Methods	Controlled before-after study. Study period April 1994 to March 2001. Pilot program ran from April 1999 to April 2000. Three years crash data for 'before' period April 1994 to March 1997, and two years 'after' data April 1999 to March 2001
Participants	Twenty experimental sites compared with ten control sites involving the cities of Copenhagen, Odense and Svendberg in Denmark
Interventions	Mobile speed cameras in operation two hours on average at varied sites on a daily basis. 105,000 cases of speeding were recorded during the one year project
Outcomes	During pilot program an overall 2.4 km/ h reduction in mean speed with only small differences between the three cities. A 10.4% reduction in % of drivers exceeding speed limit and a 4.5% reduction in those exceeding the speed limit by 10km. A 22% reduction in injurious crashes in first year and 20% in second year post intervention compared to before
Notes	Characteristics of control sites not described.

ES Barcelona

Methods	Interrrupted time series study. The study period was January 1, 2001 to March 31, 2005, consisting of a 2 year 'before' period January 1, 2001 to March 31, 2003 and an 'after' period April 1, 2003 to March 31, 2005
Participants	A 24.1 km experimental urban beltway which had 3 lanes in each direction, with posted speeds of mainly 80 km/h. The remaining sections had posted speeds of 60 km/h. The treatment section had no traffic lights
Interventions	8 overt cameras operated from 22 different sites. The cameras were moved randomly from site to site during the study period
Outcomes	The outcome measures were numbers of road crashes, numbers of people injured (combined fatal and non-fatal) and number of vehicles involved in crashes. The relative risk of a road crash on weekdays after 2 years post implementation was 0.69 (95% CI = 0.54 - 0.89) with the relative risk of injury 0.70 (95% CI = 0.53-0.92) No change of note was seen at the comparison sites. Attributable fraction estimates for the 2 years of the speed camera intervention showed 364 crashes prevented, 507 fewer people injured and 789 fewer vehicles involved in crashes. After controlling for trends and seasonality there was an estimated 26% reduction in total crashes with a similar 27% reduction in the number of injury crashes
Notes	Comparison sites were used in this study, however these sites were significantly different from experimental sites in that, they consisted of arterial roads with traffic lights, posted speeds of 50 km/h and 2 to 4 lanes. Furthermore, random mobile cameras operated on these roads from time to time.The study controlled for general trends and seasonality and discussed crash migration, time of day and traffic flow but did not account for RTM effects

FI Finland

Methods	Controlled before-after study. Study period April 1990 to December 1993. 'Before' period April 1990 to March 1992. 'After' period April 1992 to March 1994.
Participants	Experimental area was a 50km length of a two-lane stretch of highway No. 1, leading west of Helsinki. Control area was Highway No 6 leading east of Helsinki. Speed limits of 80km/h and 100 km/h on study sites.
Interventions	12 fixed camera poles distanced between 1.5km and 7km. One direction of road monitored and camera rotated randomly between poles. Duration of surveillance 8 to 36 hours, involving 8065 hours of operation between April 1st 1992 and December 31st 1993
Outcomes	On 80 km/h sections an 8% reduction of speeding vehicles seen on experimental sites compared to control sites in year one, with a further 2% decrease in year two. On 100km/h stretches a 5% reduction in number of speeders was seen in year one, with a further 2% reduction in year two. Distance halo of 3km upstream and 2km downstream. A non-significant 19% reduction in crashes (not defined) compared to controls
Notes	Crash analysis is limited as only a short follow-up period for crash data (April 1992 to December 1993). Control site characteristics apart from road type and speed limits not given. Study doesn't account for any other potential confounders either

GB 30mph Roads Nationwide

Methods	Before/after study which used U.K. national crash totals and traffic flows as a comparison group for analysis of crash effects. Speed effects were based on before/after observations with the 'before' data simply compared to the national average for cars on 30 mph roads. The study period varied depending on time of implementation across sites. Exact start and finish dates were not given, however for crashes the 'before' period consisted of 3 years of data collection at each site prior to program implementation and the 'after' period was an average 2.3 years and up to 3 years post implementation for each site. Length of study period for speed was not described
Participants	62 experimental sites on roads, all with a 30 mph speed limit in various locations throughout the UK, all with reported severe speeding problems
Interventions	Fixed overt cameras, which included warning signs. Crash data were collected for all crashes occurring up to 1km either side of the cameras
Outcomes	The outcomes measured for speed were mean speeds, 85th percentile speeds and percentage exceeding the 30 mph speed limit. Mean speeds were reduced by an average of 4.4 mph and 85th percentile speeds by 5.9 mph. There was also a 35% reduction in the percentage exceeding the speed limit. The reduction in all speed measures was statistically significant at the 5% level.The outcomes measured for crashes were personal injury crashes at various distance from the enforcement site as well as fatal and severe injury crashes. Separate crash outcome estimates are given for the effects of traffic flow and crash migration as well as for changes in general crash trends and RTM For personal injury crashes (PIA's) the observed effect for up to the 500m distance, was a 36% (-51 to -11 95%CI) reduction with a 34% (-33 to -13 95%CI) reduction in fatal and serious crashes. After adjusting for trend, the outcome translated to a 30% reduction in all PIA's with a 29% reduction in all fatal and serious crashes up to the

	500m distance. Estimates of changes in crashes attributable to RTM effects showed a reduction for both types of crashes at all distances up to 1km, The RTM effect varied from a - 4% for personal injury crashes to a reduction of -18% for fatal and serious crashes. The latter accounted for over half of the overall observed decrease in fatal and serious crashes for 500m monitoring length. After accounting for all potential confounders including changes in speed and traffic flow, the overall average effect of speed cameras on crashes was a reduction of 25% in PIA's and an average 11% reduction in fatal and serious crashes for the 500m monitoring length, with a similar average 24% reduction in PIA's and 13% reduction in fatal and serious crashes at the 1km length
Notes	The analyses included UK national crash totals and traffic flow for comparative purposes. Empirical Bayes methods were used to control for RTM, crash changes attributable to changes in traffic flow, speed behaviour and crash trends were taken into account The estimate of crash trend effects showed a conflicting average increase for personal injuries due to trend and an average decrease for fatal and serious crashes. The authors state this is a consequence of the range of implementation dates for the 62 camera sites, and that one needs to consider whilst the underlying trend is downwards for all crashes, total personal injury crashes tend to fluctuate with several year on year increases before declining again, whereas fatal and serious injuries tend to decline more consistently. Hence results need to be considered in light of implementation dates Main outcome was a fall in personal injury crashes of 25%, with 20% of this fall attributable to program impact on speed and 5% due to changes in traffic flow i.e. traffic migration

GB Cambridge

Methods	Interrupted time series design. Study period 1990 to 2002.
Participants	Drivers of motorised vehicles on designated roads in Cambridgeshire. Roads included major A roads, urban and trunk roads. Injury crash data collected over a 12 year period 1990-2002 for camera and non-camera sites. Speed data from before and after installation of cameras as well as limited data from surrounding areas during the same period plus rest of network comparison
Interventions	Progressive introduction of speed cameras from 1991 consisting of 49 overt fixed camera sites with warning signs within 1 km of camera site. Some roads had multi- camera and other stand-alone sites. Both before and after periods varied depending on implementation date. Minimum length of before period not documented. Minimum length of after period was one year
Outcomes	Outcome measures were injury crashes weighted according to the expected frequencies for each crash severity type. Time dependent coefficients were derived using all crashes in Cambridgeshire to control for RTM and time trends Mean crash count per month at camera sites weighted by severity. Estimates in crash count for different distances from camera sites. A 45.74% reduction in weighted injury crashes within 250m from camera sites (total monthly before count of 23. 4 compared to total monthly after count of 12.7) with lesser but still significant decreases observed in the wider surrounding areas such as a 20.86% reduction inside a 2000m radius from the camera. Authors concluded from the analysis of different road types that the greatest reduction in crash numbers is got from roads with the highest number of speeding offences

Notes	Extension of earlier study. Hypothecation introduced in 2000. As crash rates near camera sites reduced most, authors argue that sudden braking near camera sites is not increasing crash numbers. They also argue that little evidence exists for accident migration based on looking at the results of crash reductions at different distances from the camera sites. Authors do not provide data to show how effective their efforts were for controlling other potential confounders in this study

GB Nationwide

Methods	A before after study using two types of comparison groups, one consisting of sites within the partnership areas with no camera intervention and the other using crash data acquired from each police force across the U.K. not within the partnership area. (these non-partnership areas may have had their own camera enforcement, which were not part of the cost recovery program) Study period varied with incremental implementation of program. Scope of 4 year report covered the period April 2000 to March 2004. By the end of the study period 38 partnership regions across the United Kingdom, under the national cost recovery program, were involved. Over 20,000 speed surveys taken over 4 years from across each partnership area. Before speed data period had variable timeframe from prior to the introduction of speed cameras or from pre-existing camera sites (before becoming part of the cost recovery program) 'After' speed data between 2002 and 2004. Trends in speed at fixed camera sites (89 sites) with at least 5 'after' speed readings plus trends at mobile camera sites (63 sites) were evaluated. The crash 'before' data consisted of at least 3 years baseline and the 'after' data was collected monthly for periods of at least one year
Participants	38 partnership areas in both urban and rural locations throughout UK, involving multiple road types and speed limits
Interventions	• Fixed cameras, consisting of standard fixed cameras installed in camera housings or fixed cameras at specified distances (used to calculate 'time over distance' to provide average camera to camera speed, based on the distance between the fixed cameras divided by the time taken to travel) All fixed cameras became overt following guidelines introduced in June 2002. • Manned overt mobile speed cameras. • Red lights cameras (mainly in urban areas).
Outcomes	Speed outcomes measured: Mean speed, 85th percentile speed, percentage of vehicles over the speed limit and percentage exceeding the speed limit by more than 15mph. Speed results across all new camera sites included a 2.3mph reduction (6% reduction) in mean speed, 3.1mph reduction (7% reduction) in 85th percentile speed, 30% reduction in vehicles exceeding the speed limit and a 43% reduction in vehicles exceeding the speed limit by more than 15 mph. Time over distance cameras were shown to be particularly effective (around 100% reduction) at reducing speeds exceeding 15mph over the speed limit. In general the greatest reduction in speed (in absolute and percentage terms) against all 4 outcome measures was found at urban fixed speed camera sites.The least reduction in speed was found at rural mobile camera sites. Crash outcomes measured: Killed and seriously injured (KSIs) and personal injury crashes (PICs). Across all sites KSI's decreased by 42%. This equated to about 1700 fewer KSI's per annum at these camera sites. Fixed cameras in both urban (47% reduction) and rural areas (62% reduction) were more effective than mobile camera sites in urban (35% reduction) and rural areas (34% reduction) at reducing KSI's. Across all sites PIC's decreased by 22%. This equated to a reduction in PIC's of about 4200 at camera sites. Overall fixed sites were slightly more effective at reducing PIC's (-24%) when compared to mobile sites (-21%). Fixed camera sites in rural locations were the most effective combination at reducing PIC's (-33%) however across all sites, 85% of the reduction in PIC's was in urban areas. Crash results are consistent with speed analysis in that, fixed cameras were shown to be more effective than mobile cameras

Notes	Crash analysis accounted for speed limits, seasonality and time trends. Authors argue because no significant difference was found between fixed and red light cameras they were grouped together in the analysis as fixed cameras, however effects may be different for both camera types. Study controlled for seasonal effects and long term trend by using a general comparison group from all of the U.K. using data from areas other than the study and by comparing relative changes in injury crashes to national trends. Did not discuss potential impacts of these factors. No discussion regarding traffic volumes before and after implementation or how comparison sites matched regarding traffic flow. No discussion regarding possible crash migration effects resulting from the enforcement program. The effects of regression to the mean RTM, were considered using an empirical Bayes approach for a small sub-set of sites only. This sub-set was not representative of all camera sites nationally, consisting only of single carriageway urban roads with mainly 30 mph speed limits. Authors argue that RTM bias was not a factor because the number of crashes was not the sole criterion for site selection

GB Norfolk

Methods	Controlled before-after study. Study period October 1, 1999 to September 30, 2003 providing 24 months pre and 24 months post camera operation crash data
Participants	29 experimental sites consisting of a 72 km total road length, most with posted speeds of 60 mph or above. Typically sections of enforced roadway were about 3 km in length, although road configuration and safety considerations meant that lengths varied and mobile camera units might just operate at 1 or 2 specific points within each designated road length. The authors state that no suitable controls could be found for 10 of the experimental sites. The remaining 20 experimental sites were compared with between 12 and 44 control sites
Interventions	Mobile overt cameras at 29 sites. Deployment was mainly rural with just 2 urban experimental sites. Control sites were chosen on the basis of similar road class, road length and speed limit as experimental sites. They were also matched either on number of minor road junctions or on traffic flow averages
Outcomes	At camera sites there was a reduction of 19% for all crashes and a reduction of 44% for fatal and serious crashes. The authors state that the reduction in total crashes was significantly greater than that expected from the effect of regression to the mean in 12 out of the 20 experimental sites tested
Notes	Account was taken of RTM effects, crash migration, crash severity trends and possible road engineering events

GB South Wales

Methods	Controlled before-after study. Study period 1996 to 2000. Average length of time before intervention was 38 months and average follow-up was 17 months. Crash data (with at least one injury) for period 1996 to 2000
Participants	101 experimental sites, all types of roads in South Wales, UK with matching control sites from Gwent, a neighbouring police force area
Interventions	Mobile overt speed cameras, 12 cameras by end of 2000.
Outcomes	Rate ratio of injury crashes at intervention and control sites (0-500m route). A reduction of 50% in personal injury crashes which was sustained for two years after the intervention

Notes	Study compared various methods, circles and routes of various sizes to assess the local effectiveness of mobile speed cameras, and then used the most appropriate method found to examine speed cameras by time after intervention, time of day, speed limit, and type of road user injured. Methodology not clear in this study. Control sites matched for posted speed limit, road class and injury crash history

GB West London

Methods	Controlled before-after study. Study period 1989 to 1995. Three year 'before' period October 1989 to October 1992. Three year 'after' period October 1992 to October 1995.
Participants	Trunk and non-trunk A class roads in London. Trunk road network was 85km in length. Controls were comparable roads in other areas of London with no cameras over the same period
Interventions	21 fixed speed camera sites at start of project in 1992 (plus 12 red light camera sites) along 10 routes
Outcomes	Significant reduction in crashes, fatal, serious injuries and lesser injuries per se and in relation to controls. Greatest improvement in higher severity crash outcomes. A reduction of 12.4% for all crashes. Fatal crashes reduced by 69.4% (62 down to 19) relative to before and a significant 55.7% relative to controls. Serious injuries reduced by more than 25% from 4983 to 4375, resulting in a 31% reduction in fatal and serious crashes combined. A reduction of 7.9% in slight injury crashes was reported.
Notes	No separation of effects of red light versus speed cameras. Part control for crash trends. No control for other potential confounders

HK Hong Kong

Methods	Controlled before-after study. Study period 1998 to 2000, a period of two years. 'Before' period from January 1998 to January 1999. 'After' period from January 1999 to January 2000.
Participants	The experimental group was one 20 km section of highway in Hong Kong divided into 2km sections. The control group was other highway sections in Hong Kong where no speed camera enforcement took place
Interventions	10 fixed speed enforcement systems with two cameras operating continuously on a rotational basis (1:5)
Outcomes	65% reduction in cars travelling in excess of 15 km/h or more over the speed limit. 23% reduction in number of injury crashes compared to before period. In same period there was a 32% increase in number of injury crashes in the control group. Fatal crashes reduced by 66% in the experimental group.

Notes	No detail on characteristics of control group given. Traffic conditions and road type discussed in relation to speed camera operation but not in relation to potential confounding. Statistical methods not adequately shown. Study limitations not discussed.

NL Friesland

Methods	Controlled before-after study. Study period 1990 to 2002 in total, with an 8 year 'before' and a 5 year 'after' period for crashes. For speed, the study time was a 1 year 'before' and a 5 year 'after' period. Initially enforcement of 8 police regions occurred in 1998 and by January 2001, program implementation had occurred in all 25 police regions
Participants	Motorised vehicles on rural 80km/h and 100 km/h single carriageway roads, with a police reported high injury crash rate, in the before period of 1992 -1996. A total of 28 road sections, with a total length of 116 km with high injury crashes were subject to targeted enforcement
Interventions	The enforcement involved the use of covert, mainly mobile cameras. An average of 1 -2 hours of enforcement per site per week was implemented. For the first 3 years, deployment was around 4000 -5500 operational hours, increasing to over 14,000 hours in the 4th and 5th year. Monitoring of speed was used to re-distribute enforcement amount. For speed effects, the treatment group involved 12 road sections with a total length of 60 km/h and speed limits of 80 km/h. The control group was 15 comparable rural road sections within the province of Friesland, with a total length of 51km and speed limits of 80 km/h. For crashes, the treatment group involved all 28 speed camera enforced rural road sections, 23 of which, had speed limits of 80 km/h and 5 had speed limits of 100km/h. The control group were all other non-enforced rural roads in Friesland,approximately 5200 km in total length
Outcomes	Speed outcomes were annual mean speeds per road section and annual percentage of speeders over the targeted speed limit. The results were a non-significant mean speed reduction of 4 km/h on the enforced roads and a 1. 5km/h reduction on the control roads between 1997 and 2002. The percentage of speeders decreased by 12% on the treatment roads compared to 5% decrease on the control road sections. Greatest reductions in mean speeds and percentage of speeders occurred at the start of the enforcement program and again in 2001 when enforcement was intensified. Regarding crashes, odds ratios for injury accidents (all severities) was 0.79 (0.66-0.95) showing a 21% reduction for the enforcement period compared to the before period on the enforced sections of roads. The odds ratio for serious traffic casualties (fatalities plus hospital admissions) was also 0.79 (0.63-0.99)
Notes	Each enforced road had a posted road sign warning that stated speed camera enforcement was possible. This sign was constantly present, independent of the actual presence of enforcement. Regarding speed effects, the control group had much lower traffic volumes compared to the treatment group (3800 versus 7200 vehicles per hour in 1997) . According to the authors the odds ratios for crashes was estimated, based on relatively small numbers. Extensive weekly media coverage and a dedicated publicity officer were used for a public information and education campaign. This factor plus RTM and program spillover effects were among possible confounders. However, authors argue RTM was unlikely to be an issue because crash rate had remained similar for 8 years

NL Netherlands

Methods	Controlled before-after study. Main study conducted October 1990 to June 1991 using four experimental and four control roads for phase 1 and phase 2 study. Then phase 3 of Netherlands study conducted in September 1994, with two 'new' control roads for crash data comparisons
Participants	Four two-lane rural road stretches in four Dutch provinces, 10-17km in length. For phase 3, one road of main study, the N266 in the province of Noord-Brabant used
Interventions	Unattended fixed overt speed cameras and radar operating randomly off three or four posts installed along each of the four experimental roads from early morning until midnight. Phase 3 continuing from phase 2 also used fixed overt speed cameras and radar
Outcomes	Speed and crash outcomes. Aggregation of data from the four roads (compared to phase 0) showed a reduction in average speed of 3km/h in phase 1 and 5km/h in phase 2, a reduction in 85 percentile speed of 3km/h in phase 1 and 8km/h in phase 2. A reduction in proportion of speeders from 38.2% to 28% in phase 1 and from 38.2% in phase 1 to 11.4% in phase 2. A reduction of 35% in the total number of crashes for phase 1 and 2 compared to same period three years previously and compared to the control roads (in phase 3). Speed and crash reductions achieved in original study were maintained three years later
Notes	For phase 3 crash data on experimental road compared to 2 control roads. No control arm used for speed comparisons.

NO Nationwide

Methods	Controlled before-after study. Study period 1988 to 1993. Mean length of 'before' period was 3.94 years. Mean length of 'after' period was 4.61 years. In no case before or after period less than one year.
Participants	64 road sections each 1-2km long of a total 336.3km road network. All roads rural and two-lane in Norway where automatic speed enforcement had been introduced by 1995. Photo radar enforcement began in 1988. The total number of crashes in the rest of the country in the before and after period was used as a comparison group
Interventions	Fixed overt speed cameras.
Outcomes	A significant reduction of 20% in injury crashes equating to about 62 injury crashes per year on all 64 road sections combined. The decline in the number of injury crashes was related to the level of conformance with official warrants for the use of automatic speed enforcement (see notes). A decline of 26% in injury crashes was found on road sections conforming with both warrants. On road sections not conforming with any of the warrants, injury crashes declined by 5%
Notes	The warrants refer to crash rate (crashes/vehicle km) and crash density (crashes/km of road). Authors state frequency and duration of interventions unknown thus not possible to study the relationship between the intensity of enforce-

	ment and the size of the effects on speed and crashes. No before speed data was available to this study hence camera effects on speed are not assessed in the study. Study controlled for possible confounding due to regression to the mean, changes in traffic volume and general trends in number of crashes

NO Oslo

Methods	Controlled before-after study. Study period August 1991 to December 1991. 16 week study, two week 'before' period, six weeks enforcement, eight weeks 'after' period. Continuous speed measurement at 12 sites for 16 weeks. One experimental road divided into six sites, one control road divided into six sites
Participants	One 35km long stretch of semi rural undivided two lane road in Norway with mainly 80km/h speed limits, but some 60km/h speed limits through small more densely populated communities
Interventions	Five police patrols using stationary speed enforcement with observation units (mainly in unmarked hidden cars) measuring speed by radar or laser gun and 'stop' units using marked visible police cars to enforce. Average nine hours of enforcement daily for six weeks
Outcomes	Reduction in speed relative to the control road. Average speeds were reduced by 0.9 to 4.8km/h in both speed limit zones and for all times of day. A time halo effect of up to eight weeks was shown. The proportion of speeding drivers was reduced by 10% in both speed limit zones for all hours of day except the morning rush hours 6.00am to 9.00am
Notes	The control road was close enough to have same weather conditions but the road ran through different communities hence migration of traffic not expected, however not ascertained

NZ Christchurch

Methods	Controlled before-after study. Study period 1988 to 1997. Compared four years 'before' (1989 to 1992) data with four years 'after' data (1994 to 1997)
Participants	City of Christchurch, New Zealand. Controls were matched non-camera sites in Christchurch.
Interventions	Progressive introduction of fixed overt speed cameras in 24 speed camera zones
Outcomes	The outcome focus was all crashes rather than speed related crashes per se. Outcomes were results for all crashes and serious injury crashes. The latter combines both fatal and serious crashes. A reduction of 9.17% (S.E 5.13%) in crashes and a significant 32.4% (S.E 12.51%) in serious injury compared to New Zealand overall after four years of the intervention was reported. It was also observed that the average difference between the 85th percentile and mean speed for the four years before and four years after intervention was only 0. 8km/h

Notes	Controlled for crash trends and changes in traffic volume but not for possible regression to the mean and crash migration

NZ Nationwide

Methods	Interrupted time series design with a comparison area. This study updates an earlier study and reports results from the first 2 years post implementation. The study period was from1996 to 2002. Aggregated monthly crash data collected from November 1993. Speed data collected from July 1995 ongoing
Participants	The experimental area was the Midland Police Region of New Zealand, consisting of all 100km/h open roads in existing speed camera areas, 100km/h open roads generally, and 100km/h open roads with existing speed cameras plus new covert speed cameras. The comparison areas were 100km/h open roads in existing speed camera areas and 100 km/h roads generally, in the rest of New Zealand
Interventions	This study as previously stated, updates an earlier study and coincided with an increase in enforcement, when covert cameras were added to the 100km/h roads which already had an overt speed camera program in place. For this study, overt speed cameras were used within designated speed camera sites up to 5km in length and on open roads, most cameras were mobile and operated from the rear of a (usually unmarked) police vehicle
Outcomes	Over the first 2 years of the study mean speeds fell by 1.3 km/h and 85th percentile speeds fell by 4.3 km/h on open roads generally,compared with the rest of the country. Having controlled for season and general trends, injury crash outcomes in experimental areas relative to control areas were a net reduction of 11% (p= 0.03) in all crashes and 19% (p=0.002) in injury crashes on open roads across the region associated with the covert cameras, over and above the effects of the existing speed camera program. At speed camera sites reductions of 17% for crashes and 31% for injury crashes was reported
Notes	This study updates an earlier publication. Speed cameras were introduced to New Zealand in 1993. This study involved an increase in camera operation and enforcement and builds on results from an earlier publication by the authors. Generally the cameras in comparison areas were overt. Experimental and comparison areas were matched for level of road safety advertising, quality of roads, road use, vehicle speeds prior to the trial and unemployment rates in the regions concerned. Speed measures were speed limit and number of km above the speed limit (in 5km/h bands) An enforcement tolerance of 10km/h over the speed limit accepted

US Arizona 1

Methods	Nine month enforcement program January to October 2006 on a 6.5 mile urban freeway. Before and after study design with a comparison zone on another 48 mile stretch of same freeway. For crashes a pre =1651 days, post =244 days. Three evaluation methods were used to analyse crash data: a before after analysis with traffic flow correction, a before after analysis with comparison group and Empirical Bayes (EB) method with time-variant safety
Participants	All motorised vehicles on a limited access freeway segment of Arizona State Route 101, running through Scottsdale, Arizona
Interventions	Six fixed speed cameras at 6 stations in the enforcement zone positioned to enforce speed in either direction of travel north and southbound. Speed limit of 65 mph. Speed cameras triggered at speeds $\geq$ 76 mph

Outcomes	Both crash and speed outcomes reported. Only crash outcomes reported here as speed methods did not meet this review study criteria, in particular, before speed data was only collected during a 'warning' period. For crashes, a total crash reduction at enforcement zones of 44 to 55% was reported depending on which of the 3 analysis methods used, injury crash reduction of 46 to 56% with no reduction seen in rear-end crashes
Notes	A good study regarding examination of crash effects, which took traffic flow, trend effects and RTM into consideration. Its biggest drawback was the short program period (9 months) More information on the comparison site would have been helpful. As the authors point out, it is important to examine spillover effects, and it is hoped that a much longer and detailed examination of speed camera enforcement in Scottsdale will contribute further to the evidence base

US Arizona 2

Methods	Before and after study design with control group. Nine month enforcement program. This study was conducted on an 8 mile corridor of the Scottsdale Loop 101 urban freeway, by comparison to the 6.5 mile corridor which was the subject of the Arizona 2009 study. The focus of this second Arizona study was speed outcomes only. Before speed data from December 2005 for about 2 months prior to enforcement at 4 collection sites on treatment corridor in addition to before speed data from 4 sites at comparison segments. The latter were on loop 101 near city of Glendale about 25 miles from Scottsdale. After data was collected at 6 weeks, 5 months and 12 months, and about 6 weeks after end of enforcement period. Results from 6 weeks and 5 months showed large speed reductions at Glendale (Comparison site) so a 2nd comparison location for analysis was added (non-Loop 101, routes 202 and 51) with 2 data collection points at 8 months and 12 months (December 2006) for the new comparison site before data for 'mean speeds' only, was obtained from the Arizona Department of Transportation therefore the mean speeds for all vehicles were used to compare speed between Loop 101 and non-Loop 101
Participants	All motorised vehicles on an 8 -mile segment of Arizona State Route 101, running through Scottsdale
Interventions	Six fixed speed cameras at 6 stations in the enforcement zone positioned to enforce speed in either direction of travel, north and southbound
Outcomes	The speed analysis compared Loop 101 vs Glendale section, Glendale vs non-Loop 101 roads and Loop 101 vs non-Loop roads. At the Scottsdale sites mean speeds decreased from 70 mph to about 65 mph. Reductions in mean speeds were similar for the Glendale sites. At the non-Loop 101 sites (where no before data was available) mean speeds fluctuated between 68 and 69 mph. The proportion of vehicles in excess of the tolerated speed limit decreased from 15% in the before period, to 1-2 % in the post implementation period at the Scottsdale sites. Similar reductions were seen at Glendale. The proportion of vehicles in excess of the speed limit at the non-Loop 101 sites was only measured for the final 2 collection periods. An increase in both mean speeds and proportion of drivers over the speed limit (from 1-2% to 12% at Scottsdale) was noted soon after speed camera enforcement was suspended
Notes	The main weakness in this study was the need to use post hoc comparison sites because of what would appear to be significant spillover effects to the originally designated control sites at Glendale. Media coverage may also have confounded the enforcement effect. The fact that a lot of the positive speed reductions retracted soon after enforcement ended, is telling

US Maryland

Methods	Before and after study with comparison sites.
Participants	This was the first speed enforcement program implemented in the state of Maryland. Residential streets with speed limits of 35mph or less and school zones in Montgomery county were targeted for enforcement
Interventions	Initial enforcement carried out with 6 mobile cameras deployed in marked vans in 2007. The vans were in service from about 6 a.m. to 9 p.m. Monday through Saturday and rotated among 10 to 12 locations. During the first 6 months of enforcement, mobile cameras were deployed at about 60 locations in total and resulted in approximately 40,000 citations. Between the 5 and 6 month, the 6 mobile cameras were supplemented by 2 fixed cameras. 10 sites from 20 locations in Virginia were used as controls. Controls were matched for speed limits, road type and traffic flow. 10 similar non-enforced sites in Montgomerery but with posted speed limits of 40 mph (which were thus ineligible for enforcement) and chosen randomly were examined for 'spillover effects'. Six months of 'before' speed data and 6 months of 'after' speed data were used for the analyses
Outcomes	Outcomes measured were mean speeds and percentage exceeding speed limit by > 10 mph both for sites where cameras were deployed with warning signs installed, for sites where warning signs were installed but no cameras deployed and for the sites with 40 mph speed limits. Mean speed at the 5 sites (where cameras were deployed) decreased by 10% (range 5% -18%) The proportion of drivers travelling > 10 mph above the speed limits declined by about 70% at locations with both warning signs and speed camera enforcement, 39% at locations with warning signs only and 16% on 40 mph residential streets with neither warning signs or speed cameras
Notes	Changes in traffic volume were noted at some experimental sites which led to some sites accounting for a much larger sample size in the 'after' period compared to the 'before' period. To deal with this, overall statistics for each group of sites were computed as a weighted average of the statistics for each site, with weights defined as the proportion of vehicles observed at each site during the before period. Reasons for changes in traffic volumes were not discussed and whilst linear regression models were used to evaluate experimental site to site variability, it was not clear in this study if the comparison sites in Virginia changed in any way or remained similar during the study period

US North Carolina

Methods	Controlled before-after study. Study period for crash data consisted of a before period of 4 years and an after period of 4 months between January 2000 and December 2004. Crash data consisted of police reported accidents. Speed data was collected approximately 10 months before speed camera implementation and approximately 3 months after enforcement began on all treatment and control corridors
Participants	14 high volume urban corridors in the city of Charlotte were enforced and evaluated. Eleven urban corridors in the same city were used as the control group for comparison
Interventions	Mobile overt (marked vans)enforcement on legally designated corridors using warning signs within 1,000 feet (304. 8 metres) of a parked enforcement vehicle and a 'photo enforced' warning notice beneath all speed limit signs on the enforced corridors. Speed data was collected using induction loops at 80 points along treatment corridors and at 40 points on control corridors
Outcomes	Outcomes measured were total crashes, crash severity and crash type, mean,median, 85th percentile speeds, percentage of vehicles exceeding speed limit by >10 miles/hour and speed variance. 3 different crash data sets were analysed: Firstly using Hauer's comparison group methodology 'total crashes' were analysed for period between January 2000 and December 2003. The 2nd data set from January 2003 to July 2004 was used to analyse if regression to the mean confounded the study results and the 3rd crash data sub-set analysed data from the 5 most heavily enforced corridors

	(accounting for 90.4% of the total citations) during the period September to December 2004. The aggregated change in total crashes was a statistically significant 12% reduction for treated corridors compared to the expected number, following enforcement with speed cameras. Results from the 2nd analysis showed a 11% statistically significant reduction in crashes in the treatment group and concluded that regression to the mean was 'likely negligible' .For the 5 heavily enforced corridors a statistically significant 14% reduction in crashes for treated corridors was reported compared to the expected number. The calculated relative crash ratio (RCR) for all crashes was 0.84 with 95%CI (0. 76-0.93) day-time, and 01.04 (0.85-1.28) night-time. For injury crashes the calculated RCR with 95% CI was 0.78 (0.53-1.15) day-time and 0.75 (0.40-1.40) night-time Using GLM and logistic regression models, reported mean speeds at treatment sites were a statistically significant 0.91 miles per hour (mph) reduction after the implementation of enforcement. The control sites showed a statistically non-significant 0.29 mph mean speed reduction. The results for 85th percentile speeds were a statistically significant 0.99 mph reduction at treatment sites and a non-significant 0.30 mph reduction at control sites. Two-tailed F-tests with significance level set at 0.05 were used to test for before and after periods and day versus night. The calculated relative speed ratio RSR (relative to control) was Day 0.99 (0.76-1.23) Night 0.98 (0.76-1.20) The percentage of vehicles exceeding the speed limit by 10 mph or more decreased by a statistically significant average of 55% at treatment sites compared to control sites which showed very little change. Forty eight percent of treatment sites compared to 30% of control sites showed a reduction in speed variance although considerable difference in speed variance at the different treatment and control sites was noted
Notes	Efforts were made for controlling regression to the mean. Whether it succeeded on this count is debatable. Authors considered seasonality not to be a factor because comparison sites were subject to the same seasonal changes. Results can only be considered as a short term impact due to the short (only 4 months) 'after' data collection period. Although treatment and control sites were in the same city most of the high volume enforced corridors were in the treatment group. First time speed cameras used in North Carolina and was attended by a publicity campaign,which also involved a leaflet drop

US Washington DC

Methods	Controlled before-after study. Study period June 2000 to February 2002. Approximately three months 'before' period June to August 2000. About two months 'after' period January to February 2002. Enforcement commenced August 1st 2001
Participants	Seven experimental sites and eight control sites. Combination of residential streets, school and work zones and arterial roads in seven police patrol districts in Baltimore
Interventions	Five speed cameras in unmarked police cars deployed twice per week at each zone between 6.00am and 10.00pm, Monday to Saturday
Outcomes	Mean speeds at experimental sites reduced by a significant 14% compared to control sites. The proportion of vehicles exceeding the speed limit by more than 10mph decreased 82%
Notes	Characteristics of control sites not clearly described.

Characteristics of excluded studies *[ordered by study ID]*

Study	Reason for exclusion
Al Maseid 1997	Controlled study but no 'before' data period for comparison.
Ali 1997	Uncontrolled before-after study.
Bellotti 2001	Uncontrolled before-after study.
Benekohal 1993	Controlled before-after study however, no enforcement and data collection only averaged one hour
Bourne 1993	Uncontrolled before-after study.
Brimson 2002	Controlled before-after study however initial control sites were discarded during study when it was found that the comparison was not going to be statistically reliable and other control sites were chosen. Also it was not possible to separate out the effects of red light cameras versus speed cameras in this study
Cameron 2003	The main focus was the analyses of any interaction between speed camera enforcement and road safety mass media publicity
Casey 1993	Controlled before-after study however, the main outcome focus was effects of variable message signs rather than enforcement
Champness 2005	A one-off trial involving only one speed camera site.
Chin 1999	Uncontrolled before-after study.
Diamantopoulou 1998	Study was developed further in a later publication which was included in this review
Gunarta 2005	Matched pair study design, no control or comparison sites.
Ha 2003	Uncontrolled before-after study.
Hakkert 2000	Study design and methodology unclear.
Hirst 2005a	Focus not primarily on speed cameras but on the impact of various speed management schemes including speed cameras
Hirst 2005b	Focus not primarily on speed cameras but on the impact of various speed management schemes including speed cameras
Holland 1996	Uncontrolled before-after study.
Hook 1995	Uncontrolled before-after study.
Hooke 1996	Uncontrolled before-after study. Methodology unclear. Main focus was cost benefit analyses rather than effects on road trauma per se

(*Continued)*

Johannessen 2002	Uncontrolled before-after study.
Lund 1977	Uncontrolled before-after study.
Mackie 2003	Controlled before-after study, however unable to differentiate between effects of multiple road safety measures implemented concurrently. This study was a preliminary report by Bellotti P (TRL) which was later followed by the final report by Mackie et al (TRL) already listed in the excluded studies table
Mara 1996	Uncontrolled before-after study.
Oei 1995	Uncontrolled before-after study.
Oregon 1997	Controlled before-after study however, insufficient useable data and no further information available from source
Pigman 1989	Uncontrolled before-after study.
Povey 2003	Uncontrolled before-after study.
Rooijers 1991	Uncontrolled before-after study.
Sisiopiku	Uncontrolled before-after study.
Stradling 2002	Uncontrolled before-after study.
Swali 1993	A preliminary analysis only, whereas, the main study is included in this review
Teed 1993	Uncontrolled before-after study.
Werner 2002	No control arm used plus main focus of study was the evaluation of the effect of a variable maximum speed limit on roadway capacity, rather than the outcomes of interest in this review, speeding and injurious crashes per se
Woo 2007	Co-interventions. Speed cameras only one of the major interventions

DATA AND ANALYSES

This review has no analyses.

ADDITIONAL TABLES

Table 1. Methodological Quality of Included Studies

Study I.D.	Done	Unclear	Not done	Quality Score
CBA studies (12 indicators)				Based on: High = (Done = 10, Not clear = 2, Not done = 0) Moderate = (Done = 8, Not clear = 2, Not done = 2) Low = (< than 8 done)
AU NSW 1	5	5	0	Low
AU NSW 2	11	1	0	High
AU NSW 3	6	3	3	Low
AU QLD 1	7	5	0	Low
AU QLD 2	10	2	0	High
AU South Australia	9	3	0	Moderate
AU Tasmania	9	3	0	Moderate
AU VIC 2	11	1	0	High
AU VIC 3	10	1	1	Moderate
CA British Columbia	6	6	0	Low
CA Toronto	10	2	0	High
CA Vancouver	8	4	0	Moderate
DE Germany	6	5	1	Low
DK Denmark	7	0	5	Low
FI Finland	5	5	2	Low
GB 30mph Roads	11	1	0	High
GB Norfolk	11	1	0	High
Gb South Wales	6	6	0	Low
GB West London	6	4	2	Low

Table 1. Methodological Quality of Included Studies *(Continued)*

HK Hong Kong	4	6	2	Low
NL Friesland	10	1	1	High
NL Netherlands	4	4	4	Low
NO Nationwide	10	2	0	High
NO Oslo	10	2	0	High
NZ Christchurch	9	3	0	Moderate
US Arizona 1	10	1	1	High
US Arizona 2	9	2	1	Moderate
US Maryland	8	4	0	Moderate
US North Carolina	9	2	1	Moderate
US Washington DC	8	3	1	Fair
Time series designs (9 indicators)				Based on: High = (Done = 7, Not clear = 2, Not done = 0) Moderate = (Done = 6 Not clear = 2 Not done = 1) Low = (< than 7 done)
AU VIC 1	7	1	1	High
ES Barcelona	7	2	0	High
GB Cambridge	7	1	1	Moderate
GB Nationwide	6	2	1	Moderate
NZ Nationwide	7	1	1	Moderate

Table 2. List of variations between studies (some examples)

Total number of studies = 35 OUTCOMES REPORTED (number of studies) Speed + Crash outcomes (19) Crash outcomes only (9) Speed outcomes only (7) Halo effects (6)

Table 2. List of variations between studies (some examples) *(Continued)*

TYPE OF INTERVENTION (number of studies) Fixed overt cameras (17) Fixed overt and covert cameras (1) Mobile overt cameras (7) Mobile covert cameras (3) Mobile overt and covert cameras (4) Combined fixed and mobile overt cameras (2) Combined fixed and mobile, overt and covert cameras (1)
SETTING (number of studies) Urban (13) Rural (6) Rural and/or semi-rural (7) Mixed urban/rural/semi-rural (9)
TYPE OF ROAD Highway/motorway (9) Residential (4) Arterial (6) Trunk (3) Various combinations of above road types (13)
SPEED LIMITS (number of studies) Not specified (12) 40km (2) = 60km (1) 50km to 100km (1) 60km (2) > 60km (2) 80km (4) 100km (4) All available speeds Nationwide (3) Miles per hour (mph) speeds for UK and USA
NUMBER OF EXPERIMENTAL E AND NUMBER OF CONTROL/COMPARISON C SITES (number of studies) Number of C sites unclear (5) Number of E + C sites unclear (3) 1E + 1C = (5), 1E + 2 C(1), 2E + 1C = (1), 3E + 1C = (1), 4E + 4C = (1), 6E + 6C = (1), 7E + 8C = (1), 10E + 2C = (1), 10E + 5C = (1) 12E + 12C = (1),14E + 4C = (1), 14 E + 11C =(1), 20E + 10C = (1), 24E + 24C = (1), 28 E + 15 C) =(1), 28E + 33C=(1), 29E + 44 C= (1), 60E +20C =(1), 62E +1C =(1) Descriptions of a few thousand E sites in GB Nationwide study and 2500 sites in AU QLD 2 study by end of study periods
DURATION OF INTERVENTIONS and/or STUDY PERIODS (number of studies) Range from 9 weeks to13 years ≤ 2 years (12) 2+ to 4 (7) 4+ to 6 years (9) 6+ to 8 yrs (1) 8+ to 10 years (3)

Table 2. List of variations between studies (some examples) (*Continued)*

> 10+ years (3)
AVERAGE FOLLOW-UP PERIOD POST INTERVENTION (number of studies) Range from 2 weeks to 12 years (years) + unknown < 1 year (5) at least 1 year (2) 1 to 2 years (12) 2+ to 4 years (7) 4+ to 6 years (2) 9+ years (1)

APPENDICES

Appendix 1. Search strategy

In order to adapt to individual databases, search strategies were modified where necessary. All strategies were formulated using a combination of the following key words, using related thesaurus terms where available;

Interventions	Outcomes	Study design
Speed camera(s)	Vehicle speed	Randomised controlled trial
Safety camera(s)	Car speed	Controlled trial
Photoradar	Time and distance halos	Before and after study
Radar gun/Laser	Road traffic safety	Time series design
Speed control	Road traffic crashes	Impact study
Speed enforcement	Road traffic accidents	Intervention study
Police enforcement	Road traffic collisions	Comparative study
Speed limit(s)	Road traffic violations	Field study
Speed measurement	Road injuries and deaths	Observational study
Speed control	Road fatalities	
Road accident prevention		

(*Continued)*

Traffic accident prevention		

We searched MEDLINE, EMBASE and TRANSPORT using the following strategies;
MEDLINE and **EMBASE (WebSPIRS 1962 to May 2010)**
#1 speed near camera*
#2 safety near camera*
#3 photo near radar
#4 radar near gun
#5 automat* near enforc*
#6 #1 or #2 or #3 or #4 or #5
#7 speed* near enforc*
#8 speed* near halo
#9 road near speed* near limit*
#10 traffic near speed* near limit*
#11 # 6 or #7 or #8 or #9 or #10
#12 stud* or trial
#13 # 11 and #12
TRANSPORT (1968 to September 2009)
1. police* or speed* or vehicle* or motor vehicle* or automobile*
2. enforce* or detect* or radar* or camera* or laser* or limit*
3. #1 near #2
4. accident* or colli* or fatal* or injur* or crash* or speed*
5. reduc* or prevent* or safe* or deter* or aver* or avoid* or control* or prohib* or stop* or cut* or curtail* or decreas* or limit* or minim* or moderat*
6. #4 near #5
7. #3 and #6
8. before-after
9. before-and-after
10. before-and-after-studies
11. before-and-after-study
12. #8 or #9 or #10 or #11
13. controlled-trial
14. controlled-trials
15. #13 or #14
16. placebo-controlled
17. placebo -effekt
18. placebo-kontrollierten
19. placebo-konzepts
20. placebo-washout
21. placebogruppe
22. placebokontrollierten
23. #16 or #17 or #18 or #19 or #20 or #21 or #22
24. double-blind
25. single-blind
26. #24 or # 25
27. randomisation
28. randomization-
29. randomize
30. randomized

31. randomizing
32. randomly
33. # 27 or #28 or #29 or #30 or #31 or #32
34. comparative
35. comparative-analysis
36. #34 or #35
37. impact-studies
38. impact-study
39. impact-study-environment
40. impact studies
41. #37 or #38 or #39 or #40
42. field-studies
43. #12 or #15 or #23 or #26 or #33 or #36 or #41 or #42
44. #7 and #43

Appendix 2. Websites searched

AAA Foundation for Traffic Safety, USA www.aaafoundation.org 2004
Australian College of Road Safety www.acrs.org.au 2004
Australian Road Research Board www.arrb.org.au 2004 and 2009
Australian Transport Safety Bureau www.atsb.gov.au 2004
Belgisch Instituut voor de Verkeersveiligheid www.bivv.be 2004
British Road Federation www.brf.co.uk 2004
Canada Safety Council www.safety-council.org 2004
Centre for Accident Research and Road Safety; Queensland, Australia www.carrsq.qut.edu.au 2009
Community Research and Development Information Service www.cordis.lu/en/src/ 2004
Danish Road Directorate www.vejdirektoratet.dk/roaddirectorate 2004 and 2009
Danish Transport Research Institute (Danmarks Transport Forskning) www.dtf.dk 2004 and 2009
Department of Environment, Transport and Regions, UK www.detr.gov.uk 2004
Department of Transport, UK www.dft.gov.uk (Road safety research compendium) 2004 and 2009
Deutscher Verkenrssichereitsrat Road Safety Institute www.dvr.de 2004
European Transport and Safety Council www.etsc.be 2004
Global Road Safety Partnership grsp@ifrc.org 2004
Highway Safety Research Centre, University of North Carolina www.hsrc.unc.edu 2004 and 2009
Hong Kong Society for Transportation Studies http://home.netvigator.com/~hksts/home.htm 2005
Information and Technology Centres for Transport and Infrastructure) www.crow.nl2004
Injury Research Centre, Department of Public Health, University of Western Australia www.irc.uwa.edu.au 2004
Institut National de Recherché sur les Transports et leur Securite www.inrets.fr 2004
Institute for Road Safety Research -Netherlands www.swov.nl 2004 and 2009
Institute of Transport Economics Norway (Transportokonomisk institutt) www.toi.no 2004 and 2009
Institute of Transportation Engineers www.ite.org 2004
Institute of Transportation Studies, University of California www.its.berkeley.edu/ 2004
Institution of Highways and Transportation www.iht.org/ 2004
Insurance Institute for Highway Safety (Status Reports) Arlington, VA www.highwaysafety.org 2004
Land Transport Safety Authority New Zealand www.ltsa.govt.nz/roads/crash 2004
Leeds University - Institute of Transport Studies www.leeds.ac.uk/research/index.htm 2004
Liikenneturva - The Central Organisation for Traffic Safety in Finland www.liikenneturva.fi/ 2004
London University (Imperial and UCL transport group) www.ic.ac.uk 2004
Monash University Accident Research Centre, Victoria www.general.monash.edu.au/muarc/ 2004 and 2009
National Highway Traffic Safety Administration USA www.nhtsa.dot.gov 2004 and 2009
National Safety Camera Partnerships www.nationalsafetycameras.co.uk/ 2004, 2005 and 2009
New Zealand Institute of Highway Technology www.nziht.co.nz 2004 and 2009
Nordic Road & Transport Research www.vti.se/nordic/ 2004 and 2009

Office of Road Safety for Western Australia www.officeofroadsafety.wa.gov.au 2004
Organisation for Economic Co-operation and Development www.oecd.org 2004
Roads and Traffic Authority, New South Wales. www.rta.nsw.gov.au 2004
Swedish National Road Administration (Vaqverket) 2004
Swedish National Road and Transport Research Institute www.vti.se 2004 and 2009
Texas Transportation Institute www.tti.tamu.edu/research/ 2004
The International Association of Traffic and Safety Science, Tokyo, Japan 2005 www.iatssforum.jp/english/contact.html
The Netherlands Transport Research Centre (Adviesdienst Verkeer en Vervoer) 2004
Transport Canada www.tc.gc.gov 2004
Transport Research Laboratory UK www.trl.co.uk 2004
Transport Research, Technical Research Centre of Finland,Espoo www.vtt.fi/transport/ 2004
Transportation Research Board USA www.nas.edu/trb/ 2004 and 2009
US Department of Transport -Federal Highways Administration www.fhwa.dot.gov 2004
VicRoads www.vicroads.vic.gov.au 2004
World Health Organisation, Geneva, Switzerland. www.who.int/en/ 2004 and 2009

WHAT'S NEW

Last assessed as up-to-date: 10 January 2006.

Date	Event	Description
7 September 2010	New citation required and conclusions have changed	The search for studies has been updated. Nine trials have been added to the review. The conclusions and implications for practice have changed

HISTORY

Protocol first published: Issue 1, 2004

Review first published: Issue 2, 2006

Date	Event	Description
11 September 2008	Amended	Converted to new review format.

CONTRIBUTIONS OF AUTHORS

Contribution of authors by list of tasks:

Protocol development for this systematic review - Willis C, Lybrand S, Bellamy N.

Literature searches - Wilson C, Willis C.

Short-listing of studies - Wilson C.

Selection of studies for inclusion - Wilson C, Willis C, Le Brocque R.

Development of data extraction form - Wilson C

Development of quality rating tool - Wilson C, Hendrikz JK.

Piloting of quality and data extraction tools - Wilson C, Willis C, Bellamy N.

Data extraction - Wilson C, Willis C, Hendrikz JK. Le Brocque R.

Quality assessment - Wilson C, Willis C. Le Brocque R.

Syntheses of results - Wilson C, Hendrikz JK.

Manuscript write-up - Wilson C.

Manuscript review pre-submission - Wilson C, Willis C, Hendrikz JK, Le Brocque R, Bellamy N.

Project supervisor - Bellamy N.

DECLARATIONS OF INTEREST

None known.

SOURCES OF SUPPORT

Internal sources

- The University of Queensland (infrastructure), Australia.

External sources

- Motor Accident Insurance Commission, Australia.
- SWOV, Netherlands.

The librarians at the Institute for Road Safety Research (SWOV) in the Netherlands ran a search for us in order to capture any relevant studies from the Nordic countries possibly not published in English.

DIFFERENCES BETWEEN PROTOCOL AND REVIEW

This systematic review is based on the specifications within the protocol and follows on as a natural expansion, with no differences or conflict between protocol and review. However, the title used for the protocol 'Speed enforcement detection devices for preventing road traffic injuries' has been changed to a less cumbersome and easier to find title for the review, and is now titled 'Speed cameras for the prevention of road traffic injuries and deaths'.

INDEX TERMS

Medical Subject Headings (MeSH)

Accident Prevention [*instrumentation; methods]; Accidents, Traffic [*prevention & control; statistics & numerical data]; Controlled Clinical Trials as Topic; Photography [instrumentation]; Radar [instrumentation]; Safety

MeSH check words

Humans