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LITERATURE REVIEW | NOVEMBER 2011

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ABOUT THE NATIONAL COLLABORATING CENTRE FOR HEALTHY PUBLIC POLICY

The National Collaborating Centre for Healthy Public Policy (NCCHPP) seeks to increase the expertise of public health actors across Canada in healthy public policy through the development, sharing and use of knowledge. The NCCHPP is one of six Centres financed by the Public Health Agency of Canada. The six Centres form a network across Canada, each hosted by a different institution and each focusing on a specific topic linked to public health. In addition to the Centres' individual contributions, the network of Collaborating Centres provides focal points for the exchange and common production of knowledge relating to these topics.

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1 INTRODUCTION

1.1 DEFINITION OF THE OBJECT

This literature review examines the effects of traffic calming in urban environments on four health determinants, namely:

- The number and severity of road collisions,[1]
- Air quality,
- Environmental noise, and
- Physical activity associated with active transportation.

Traffic calming is a manner of intervening in the built environment that appears to offer significant potential as a way to improve population health, and the evaluative literature is sufficiently abundant to require a literature review. This review will also facilitate comparison of the two approaches to traffic calming: the black-spots approach and the area-wide approach.

As specified in our document introducing the concept of traffic calming,[2] there exists no consensus as to the precise contours of the concept in question, hence the importance of making explicit and providing the rationale for our working definition.

The concept of traffic calming as used in this literature review refers to engineering measures (speed humps, curb extensions, etc.) and to strategies structuring their implementation (30-km/h zones, meeting zones, etc.)[3] whose purpose is to reduce vehicle speeds[4] and/or traffic volumes on existing public roads to achieve various goals and objectives. These strategies are based either on a black-spots approach (where isolated measures are installed at specific points on the road network) or on an area-wide approach (where measures are installed in a systematic and integrated manner within a geographic area comprising several streets).

Thus, the concept of traffic calming as used here refers to engineering measures, strategies and approaches that, concretely speaking, vary in terms of their goals and objectives. Regarding these measures, there is a clear lack of consensus as to what precisely is meant by the term "engineering measures." While everyone agrees that devices such as speed humps or curb extensions with pedestrian crosswalks are included under this designation, views diverge significantly concerning what is excluded. For most authors, in fact, road signs

1 The term "collision" has been chosen instead of the term "accident," because the latter refers not only to an impact between two bodies, but also connotes an event of a random chance occurrence, i.e. one that is of an *accidental* nature. In this respect, the term "collision" seems more neutral and thus directs discussion more toward risk factors (Stewart & Lord, 2002).

2 For more information on the origins of this working definition, please see our document entitled "Traffic Calming: An Equivocal Concept" at: http://www.ncchpp.ca/175/publications.ccnpps?id_article=648.

3 The glossary, in Appendix 2, describes and illustrates each traffic-calming measure mentioned in this literature review. It also lists their most common names in English and in French.

4 In urban settings, traffic calming is usually aimed at reducing the speed of motor vehicles relative to the 50-km/h norm, established in the mid-20th century.

are excluded, except when they serve to indicate, for example, a speed limit of 30 or 40 km/h at the entrance to areas where speed humps or other devices of this nature have been installed. Some definitions diverge specifically with regard to the use of stop signs. For some authors, stop signs cannot be considered traffic-calming measures, whereas others include them when they are installed as part of an area-wide calming strategy. Thus, road signs were included in many of the evaluative studies considered in the present literature review. The results associated with road signs were therefore reported, not only because they are included within the perimeter of study of some evaluations, but also because some engineers developing intervention strategies themselves view these as belonging to the repertory of traffic-calming measures.

With regard to strategies, these are based on one of two approaches: the black-spots approach, which favours interventions at one or more discrete points considered in isolation from the road network, and the area-wide approach, which underpins interventions applied on a more or less large geographic scale.[5]

In Canada, calming strategies based on the black-spots approach predominate. They rest on the idea that the road network is, in general, designed to be safe and that it is well-adapted to the various uses of public roads and their associated functions, but that it contains some isolated design flaws, that require correcting, whether through traffic-calming measures or otherwise. Figure 1 depicts a map produced by the City of Edmonton that illustrates this approach. The map shows the location of "black spots," that is of places considered to be high risk–in this case, intersections where, during 2007, 40 or more collisions occurred.[6] The city's authorities make use of these black-spots analyses to guide their choice of interventions aimed at improving road safety, including those that can be considered as traffic-calming measures. Installation of such traffic-calming measures is usually aimed at improving safety at specific points on the road network, particularly by reducing motor vehicle speeds.

[5] This distinction is also made using the expressions "targeted approach" and "systemic approach."

[6] There is no standard or single criterion for defining a black spot–practices vary from one city to another.

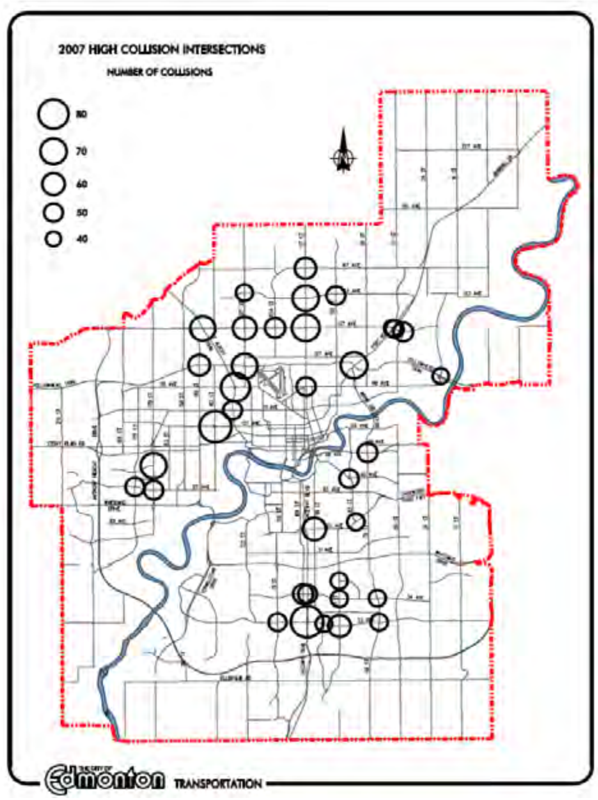

Figure 1 An example of the black-spots approach

This map identifies the most high-risk sites on the city of Edmonton's road network (40 or more collisions in 2007). The number of collisions thus mapped is significant (2724) even though this represents only about 10% of all the collisions that occurred during the same year in the city.

Source: City of Edmonton, 2008, p. 29.

As regards calming strategies based on the area-wide approach, these are still rare in this country, although some have been implemented in a few cities, in particular, Vancouver, North Vancouver, Toronto, Ottawa and, more recently, in the Plateau-Mont-Royal borough of Montréal.[7] Area-wide strategies usually rest on the idea that the road network design in certain areas of varying size is systematically biased in favour of motorized traffic, to the detriment of other modes of travel (cycling, walking, etc.) and other uses of urban space (homes, schools, meeting areas, etc.). Area-wide strategies are thus intended to help correct this bias.

[7] A Transport Canada (2005) document identifies many more Canadian cities as having implemented area-wide strategies than we have included here. The difference between the authors' working definition of an "area-wide strategy" and ours probably, to a large degree, explains this discrepancy, but the document in question does not allow for a detailed comparison of these definitions.

To this end, the installation of calming measures on a road network is systematically planned, in general so as to reduce driving speeds, but often also to reduce the volume of "through traffic" on local streets.[8] This "through" traffic makes use of streets, whose main function is residential, to travel across a given sector instead of using roads specifically intended for this purpose, namely arteries and highways. Figure 2 depicts a map of the largest 30-km/h zone in France that illustrates the potential geographic scope of strategies based on the area-wide approach.

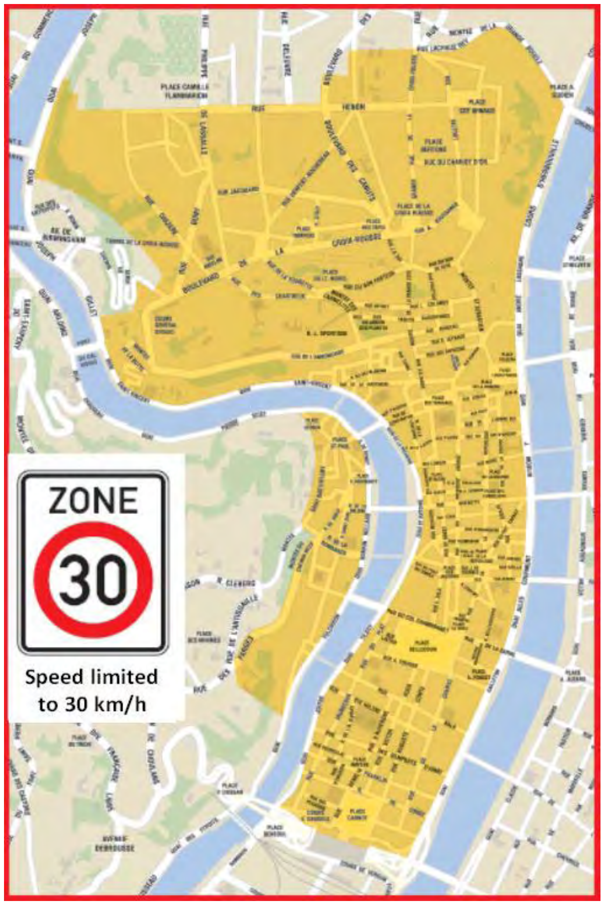

Figure 2 An example of the area-wide approach

The largest 30-km/h zone in France covers 87 km of residential streets in the central boroughs of Lyon (transit roads are not affected). Installation of these calming measures began in 2003 and is still underway.

Source: adapted from Grand Lyon / Communauté urbaine de Lyon/France, 2007.

[8] The streets in an urban road network are usually classified hierarchically, based on function, into three categories: local streets, collector streets, and arteries. Local streets are those whose main function is to allow access to residences on the street. Collector streets, between local streets and arteries, are those whose purpose is to allow access to residences and businesses as well as to collect through traffic and direct it to arteries. As for arteries, their main function is to allow the passage of through traffic.

The present literature review is organized so as to allow for comparison of the effects, in an urban setting, of strategies based on the two approaches to traffic calming.[9] Table 1 summarizes the principal characteristics of these approaches.

Table 1 Principal characteristics of the two approaches to traffic calming

	Black-spots approach	Area-wide approach
Conception of the problems to be addressed	Isolated design flaws on certain public roads.	Systematic bias of roads and of the public road network in favour of motorized traffic, to the detriment of other modes of travel and other uses of adjacent areas.
Scale of interventions	Specific points on the road network (intersection, street block or, sometimes, an entire street).	More or less extensive geographic areas comprising several streets.
Goals	Mainly the improvement of road safety.	Improvement of road safety and, more broadly, of the living environment (noise, air quality, active transportation, green space, etc.).
Means	Calming measures principally aimed at reducing motor vehicle speeds and, more rarely, traffic volumes.	Integrated series of calming measures aimed at reducing motor vehicle speeds and traffic volumes (in the latter case, usually by channeling traffic toward arterial networks or highways).

1.2 INTERVENTION LOGIC

The effects of traffic-calming measures and strategies on the four health determinants considered in this review (number and severity of collisions, air quality, environmental noise, and active transportation) are usually conceived of as being linked–directly or indirectly–to the two main mechanisms of action associated with such measures, namely, the reduction of driving speeds and of traffic volumes at intervention sites. Moreover, some authors (Ewing, 1999; Transportation Association of Canada [TAC] & Canadian Institute of Transportation Engineers [CITE], 1998) use the two main mechanisms of action to classify traffic-calming measures into two broad categories: those used to reduce driving speeds and those used to reduce traffic volumes. These two categories are often further divided into sub-categories. Calming measures used mainly to reduce speeds are classified into three sub-categories: vertical deflections (e.g., speed humps) which, as the name indicates, vertically deflect vehicles; horizontal deflections (e.g., chicanes) which laterally deflect vehicles; and road narrowings (e.g., chokers). Calming measures used to reduce traffic volumes are divided into two sub-categories: those that reduce road capacity (e.g., reduction in the number of lanes) and those that alter street connectivity (e.g., diagonal diverters). Figure 3 summarizes this classification scheme.

[9] To learn more about the political contexts within which traffic-calming interventions are developed, refer to our document entitled "Traffic Calming: Political Dimensions" at: http://www.ncchpp.ca/175/Publications.ccnpps?id_article=670.

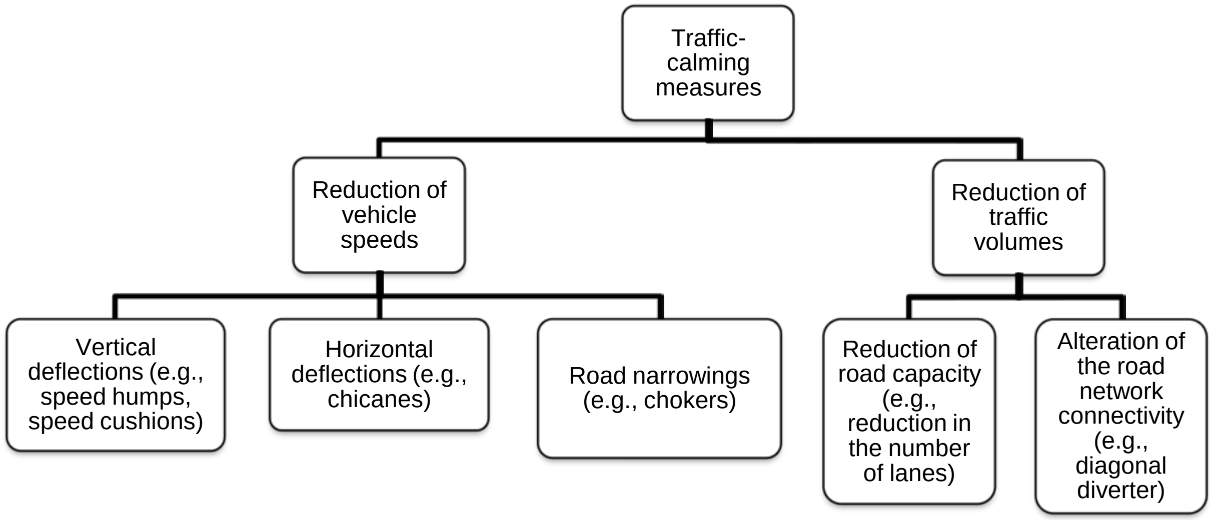

Figure 3 Classification of principal traffic-calming measures

Although the effectiveness of traffic-calming measures at reducing traffic speeds and volumes may vary according to the context in which measures are implemented and the strategies guiding their implementation, this effectiveness has been relatively well-documented and tested (TAC & CITE, 1998; Ewing, 1999; Ewing & Brown, 2009). Therefore, the present literature review foregoes an examination of this aspect to concentrate on the effects of these measures on health determinants. Figure 4 graphically summarizes the intervention logic in its simplest form. The model links the two approaches to traffic calming to their effects on health determinants by means of their preferred mechanisms of action. These mechanisms are presented in a manner that takes into account the fact that, by reducing traffic speeds, one may also seek to reduce traffic volumes. The idea, then, is that reducing speeds would make a travel route less attractive to motor vehicles than other routes towards which one desires to channel them.

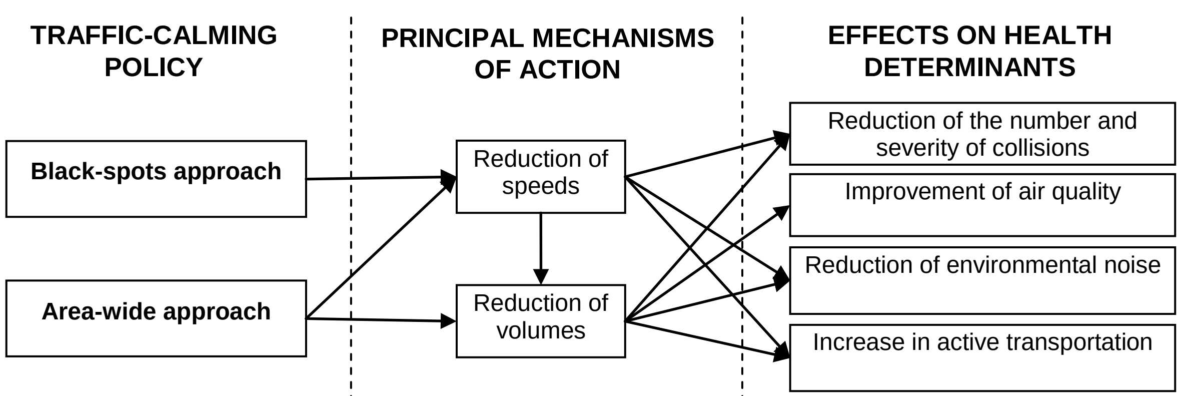

Figure 4 Intervention logic of traffic calming

This simplified diagram presents the two main mechanisms of action as they are described in the traffic-calming literature, thus excluding several mechanisms that more specifically target one or several health determinants (e.g., improvement of pedestrian visibility→ reduction in number and severity of collisions). It also excludes intermediary effects between the mechanisms shown and the effects on health determinants (e.g., reduction of speed→ enhanced perception of safety→ increase in active transportation), as well as potential interactions between health determinants (e.g., decrease in the number and severity of collisions → enhanced perception of safety → increase in active transportation). Finally, because the diagram represents the logic of the intervention and not its actual effects, potentially negative effects on health determinants are not included (e.g., reduction of speeds → increased emission of pollutants per vehicle → deterioration of air quality). These elements excluded from the diagram will be addressed in the sections specific to the four health determinants. In addition, readers will find a more detailed version of this illustration in Appendix 1.

1.3 WORKING PROPOSAL AND ORGANIZATION OF THE LITERATURE REVIEW

The literature review is organized so as to allow for comparison of the effects on four health determinants of strategies based on the two approaches to traffic calming, implemented in an urban setting. *A priori*, it seems likely that strategies based on the area-wide approach have greater potential for improving population health than strategies based on the black-spots approach. Indeed, strategies based on the area-wide approach favour interventions implemented on a larger geographic scale (networks comprising more than one street), they are often driven by broader objectives and goals (road safety and improvement of the living environment) and they tend to involve both the main mechanisms of action associated with calming measures (reduction of traffic speeds and volumes) rather than just one. The intent of this literature review is to allow for an informed discussion of this theoretical advantage.

The literature review is divided into four main sections, each covering one of the aforementioned health determinants. These sections are themselves divided into two sub-sections, one presenting the results of studies allowing for evaluation of the effects of the black-spots approach and the other presenting the results of studies allowing for analysis of the effects of the area-wide approach. In addition, the results are presented so as to distinguish between studies whose approach is objective and those whose approach is subjective.[10] Each section begins by identifying the mechanisms of action associated with the calming strategies specifically tied to the health determinant discussed in the section, and concludes by summarizing the results and identifying research gaps.

[10] By objective research, we mean research that develops and seeks to measure objects of study that are considered to exist and be measurable whether or not they are perceived by particular persons. For example, researchers have attempted to determine the influence of the built environment on modes of travel by measuring indicators such as the number of pedestrians and cyclists, building density, the level of mixed usage, the connectivity of road networks, the proximity of parks and other recreational areas, the number of calming measures, etc. By subjective research, we mean research that develops and seeks to measure objects of study whose existence is based on the perceptions of particular individuals under study. Returning, partially, to the same example, other researchers have evaluated the relationship between the use of parks and recreational areas and nearby residents' perceptions of their user-friendliness (safety, cleanliness).

2 METHOD

The documentary search was carried out during May and June 2010, and scanning continued until the end of October 2010.

2.1 DOCUMENTARY SOURCES AND RESEARCH METHODS

Given that the expression "traffic calming" has been the standard in the English literature since 1999 (Ewing, 1999), databases were searched using this key expression. Tests carried out in PubMed and MedLine using the expressions "traffic abatement," "traffic mitigation," "traffic management," "traffic control," and "traffic moderation" confirmed that, for the period covered, the articles concerning traffic calming could be located by relying on the expression "traffic calming." For the French literature, searches were carried out using the expressions "*apaisement de la circulation*," "*modération de la circulation*," and "*modération de la vitesse*." Given the diversity of the potential effects of traffic calming on health, the searches were carried out by simply entering the key expressions in the "title" and "keyword" fields.

The following databases were searched:

- PubMed;
- The Transportation Research Information Services (TRIS) database;
- Scopus;
- Scirus;
- IngentaConnect;
- Repère;
- Using the CSA Illumina platform (ERIC, Health and Safety Science Abstracts, PILOTS Database, CSA Sociological Services Abstracts, CSA Sociological Abstracts, CSA Worldwide Political Science Abstracts, Recent References Related to the Social Sciences);
- Using the EBSCOhost platform (Medline, PsycINFO, SocIndex, E-Journals, CINAHL);
- Using the OvidSP platform (Ovid MedLine (R), EMBASE, EBM Reviews–Cochrane Database of Systematic Reviews, EBM Reviews–ACP Journal Club, EBM Reviews–Database of Abstracts of Reviews of Effects, EBM Reviews–Cochrane Central Register of Controlled Trials, EBM Reviews–Cochrane Methodology Register, EBM Reviews–Health Technology Assessment, EBM Reviews–NHS Economic Evaluation Database, Global Health).

The Google and Google Scholar search engines were searched using the French and English key expressions, to extend the scope of the search. Several websites were also consulted, including in particular:

- Transport Canada (Canada), http://www.tc.gc.ca/eng/programs/environment-utsp-trafficcalming-1172.htm;

- Transportation Demand Management Encyclopedia, Victoria Transport Policy Institute (Canada), http://www.vtpi.org/tdm/tdm4.htm;
- Conseil régional de l'environnement de Montréal (Canada), http://www.cremtl.qc.ca/index.php?id=648;
- The City of Ottawa (Canada), http://www.ottawa.ca/residents/onthemove/driving/traffic/atm/appendices/appendix_c_en.html;
- The City of Toronto (Canada), http://www.toronto.ca/transportation/traffic/traffic_calming.htm;
- The City of North Vancouver (Canada), http://www.cnv.org//server.aspx?c=3&i=275;
- Institute of Transportation Engineers (United States), http://www.ite.org/traffic/;
- U.S. Department of Transportation, Federal Highway Administration (United States), http://www.fhwa.dot.gov/environment/tcalm/;
- Pedestrian and Bicycle Information Center (United States), http://www.walkinginfo.org/index.cfm;
- Transport Research Laboratory (England), http://www.trl.co.uk/default.htm;
- Centre d'études sur les réseaux, les transports, l'urbanisme et les constructions publiques (France), http://www.certu.fr/;
- SWOV Institute or Road Safety Research (Netherlands), http://www.swov.nl/index_uk.htm.

Documents were also located through "snowballing," a method using bibliographies as the means to find other pertinent resources.

2.2 INCLUSION AND EXCLUSION CRITERIA

Content of documents

To be selected for purposes of analysis, documents had to evaluate at least one effect on a determinant of population health caused by: 1) at least one intervention aimed at calming traffic on existing streets in an urban setting or; 2) traffic-calming measures installed on test tracks for evaluation purposes. Interventions in rural settings were excluded, because they most often involve installations aimed at slowing down drivers travelling through inhabited zones on roads that, outside of these zones, are designed for high speeds–a situation that applies imperfectly, if at all, to urban settings. Following a preliminary reading of the documents, it became evident that the studies centred around four health determinants, namely, the number and severity of collisions, air quality, environmental noise, and active transportation. The documentary search then continued, with only documents focused on at least one of these four determinants. Documents in which methodologies for evaluating an effect were developed without that effect being measured and those focused on the economic costs of traffic-calming strategies and measures were excluded.

Countries studied

In addition to studies examining Canadian experiences, studies focused on the United States, European countries, and Australia were included, because these countries were judged to be sufficiently similar to Canada.

Period considered

The period extending from January 2000 to May 2010 was considered during the documentary search of databases. Scanning was subsequently carried out until the end of October 2010. The search was broadened using “snowballing.” Some indispensable documents on little-documented aspects were added as a result, even though they were not published within the period initially considered.

Languages

The documents selected were written in English or French.

Methodological quality of studies

Studies using a simple before-and-after design to evaluate the effect of calming measures by comparing the number and severity of collisions at specific points in time were not retained, because these studies were shown to be marred by significant bias (see section 3.1.2.1, Box 1). No other systematic exclusion based on methodological criteria was carried out. Studies based on both objective and subjective epistemological approaches were included in this literature review. Moreover, there were no exclusions on the basis of method of inquiry, data collection technique or analytical procedures employed.[11]

In the case where the methodology used in a particular study was likely to affect its validity (conceptual, internal, external) or the reliability of its results, comments to this effect were included where the study was presented. In this regard, several of the studies included in this literature review do not indicate whether tests of statistical significance were carried out. This absence of this statistical information does not imply that relevant statistical analyses were not carried out, but neither does it allow us to conclude that they were. To draw the reader’s attention to this fact, we have mentioned it in the text and in the summary tables where these studies are presented (Appendix 3). Overall evaluations of the methodological strengths and weaknesses of the studies selected and of their implications for the robustness of results are, for their part, integrated into the various section summaries and discussed in the Conclusion.

[11] A single before-after type study (Lindenmann, 2005) focused on the effectiveness of 30-km/h zones installed in Switzerland at reducing the frequency and severity of collisions was excluded from the literature review for reasons relating to conceptual clarity. The severity of collisions, for example, is expressed therein as a function of the number of “accident victims,” but this term is not defined. Moreover, the results concerning collisions are classified according to three collision occurrence patterns (case 1, case 2, case 3), for which no explanations are given. This exclusion should not affect the results of this review, since the conclusions the author of the study draws from his data are in line with those presented in this literature review (that is, a reduction in the number and severity of collisions after areas are calmed).

2.3 SELECTED DOCUMENTS

Following verification of their conformity to the inclusion and exclusion criteria, the documents selected for the purpose of analyzing the results of the evaluative research included 19 drawn from the scientific literature (peer-reviewed articles published in scientific journals) and 10 drawn from the grey literature (reports and conference presentations).

To determine the effects of the different health determinants on population health, the mechanisms of action of the calming measures, research gaps, and methodological problems, we broadened the documentary search and extended the inclusion and exclusion criteria. Studies that were not directly focused on calming measures, but on their mechanisms of action, for example, were thus included, along with studies focused on methodologies or traditional literature reviews identifying research gaps. In this manner, 36 documents drawn from the scientific literature and 38 documents drawn from the grey literature were added to the literature review.

To allow readers to distinguish between studies drawn from the scientific literature and those drawn from the grey literature, the term “article” was reserved for studies drawn from the scientific literature, whereas the terms “report” and “conference presentation” were systematically reserved for the grey literature. The term “study” for its part, was used generically to refer to either.

2.4 PERUSAL AND EXTRACTION OF EVALUATIVE DATA

All of the documents retained for the purpose of analyzing the results of the evaluative research were obtained and read in their entirety by both authors of this review. They then compiled the data in extraction tables, systematically considering the questions asked by the studies' authors, the methodology used, the answers given to the questions, conceptual and internal validity and the reliability of results. Differences in interpretation were resolved through consensus. These tables are presented in Appendix 3.

2.5 CLASSIFICATION OF EVALUATIVE STUDIES

The results of the evaluative studies were classified according to the two approaches to traffic calming and the four health determinants covered in this literature review. Separating studies examining area-wide strategies from those examining black-spots strategies is an exercise that presents challenges. In reality, although traffic-calming interventions are quite diverse (types of calming measures, combinations, number, density, extent of geographic area calmed, etc.), they are rarely precisely described in evaluative studies and the logic having governed the installation of calming measures (black-spots approach, area-wide approach) is still less often explained.

When the intervention logic is not made explicit, it is standard practice in the literature on traffic calming in general, and in that evaluating collisions, injury and death in particular, to separate evaluative studies on the basis of the geographic extent of the interventions considered (at one spot, along a line, for example, a street block or an entire street, or within a geographic area, that is, a network of more than one street). Studies evaluating the effects of a series of calming measures installed in a geographic area comprising several streets are used to provide information about the effects of calming strategies based on the area-wide approach. As for studies evaluating the effects of isolated calming measures installed at specific points on the road network, they are undertaken to evaluate either the effects of one calming measure (e.g., those of speed humps), of one type of calming measure (e.g., those of vertical deflections), or of the black-spots approach in general, since isolated interventions are usually the product of strategies based on this approach.

The classification of interventions involving several calming measures installed on a street block, or even on an entire street, is more controversial: they are sometimes included in the first category (Bunn et al., 2003; 2009) and sometimes in the second (Elvik, 2001; Boulter & Webster, 1997).

This classification of studies according to the geographic extent of the interventions examined has its limitations within the context of this literature review, for it presupposes that the geographic extent of the interventions evaluated is indicative of the logic that governed the planning and installation of the calming measures evaluated. It is possible, for example, for a calming measure’s effectiveness at reducing collisions, injuries and deaths to be evaluated at a specific point on a road network, even though the measure is part of a configuration of calming measures that was planned for and installed on a network comprising several streets. However, despite its limitations, the geographic extent of the interventions evaluated by a study remains the best criterion for classifying it, when the intervention logic is not specified.

In this literature review, evaluative studies were thus classified according to the intervention logic (black-spots/area-wide), when this was specified, and according to the geographic extent of the interventions evaluated, when the logic was not made explicit. Since interventions on a street block or an entire street are not generally designed to reduce traffic volume by redirecting through traffic toward arteries and highways, they are thus most similar to isolated interventions installed at specific points on the road network, intended mainly to reduce driving speeds. Moreover, some discrete calming measures (chicanes, road diets, etc.) can only be installed on street blocks or along entire streets. For these reasons, we opted for the classification system adopted by Elvik (2001) and by Boulter & Webster (1997). We thus classified these studies alongside those focused on isolated interventions at specific points on the road network, so as to glean from them information about the effects of strategies based on the black-spots approach. Studies focused on interventions installed in a geographic area comprising several streets were, for their part, used to enhance understanding of the effects of strategies based on the area-wide approach. To allow readers to classify these studies differently, the tables summarizing the evaluative studies included in this literature review are presented in Appendix 3. Interventions involving several calming measures installed on a street block or on an entire street are there presented as a separate category.

3 SYNTHESIS OF DATA DRAWN FROM THE LITERATURE

3.1 NUMBER AND SEVERITY OF COLLISIONS

Motorized traffic is responsible for a significant number of injuries and deaths occurring when collisions take place or in their aftermath (World Health Organization [WHO], 2009; Canadian Institute for Health Information [CIHI], 2010). In Canada, for 2006, the number of deaths[12] caused by road collisions was evaluated at 2889 and the number of injured at 199,337 (WHO, 2009). Collisions involving motor vehicles were also responsible for 42% of hospitalizations due to serious injury in Canada for the 2007-2008 period (WHO, 2007; CIHI, 2010). Interventions aimed at improving the road safety record are usually classified into four categories depending on whether their aim is to modify individual behaviour (e.g., campaigns to raise awareness about the dangers of driving while fatigued), construction norms for vehicles (e.g., air bags), the physical environment (e.g., traffic-calming measures) or the social and political environment (e.g., criminalization of impaired driving) (Haddon, 1980). Interventions targeting the physical environment, such as traffic-calming strategies, have the advantage of not depending on the presence of the police force to be effective. In addition, they have the potential to improve the safety of all road users. Finally, since the lowest-income population segments and those with the lowest socioeconomic status (SES) are often overrepresented in road fatalities and injuries in urban settings (WHO, 2004; Laflamme, Hasselberg, & Burrows, 2010; Cubbin & Smith, 2002), these interventions can help to reduce health inequalities (Jones, Lyons, John, & Palmer, 2005; Morency & Cloutier, 2005; Grundy, Steinbach, Edwards, Wilkinson, & Green, 2008a). These are the main reasons that traffic-calming strategies–in conjunction with other interventions–are being promoted.

3.1.1 Mechanisms of action

According to the studies consulted, traffic-calming strategies can influence road safety results by means of six main mechanisms:

a) Reduction of vehicle speed

Research shows that the number and severity of collisions increases with speed (Sergerie et al., 2005). A report even suggests that each decrease of 1.6 km/h in an urban setting results in a 3 to 6% decrease in collisions, depending on how major a road is being considered [Taylor, Lynam, & Baruya, 2000]). As Figure 5 illustrates, increasing speed decreases a driver's field of vision, which goes from slightly wider than 150 degrees at very slow speeds to around 75 degrees at 100 km/h, thus reducing the likelihood that a dangerous situation will be noticed in time. Moreover, increasing speed increases stopping distance, that is, the distance travelled by the vehicle during the time it takes a driver to react plus the vehicle's braking time, which accordingly reduces the likelihood that the vehicle will stop in time to avoid a collision or that it will have slowed down enough to avoid a serious collision. For example, a car travelling at 30 km/h on dry pavement, and whose driver takes two seconds to react, will stop after travelling a distance of a little over 20 metres. At 50 km/h, the same car would have travelled twice that distance, a little over 40 metres (Bureau de prévention

[12] The WHO defines a road fatality as a death caused by a road collision, occurring either at the time of collision or in the subsequent thirty days (WHO, 2004).

des accidents, 2008a). The seriousness of collisions also increases with speed, especially when vulnerable road users, such as pedestrians and cyclists, are involved. As Figure 6 shows, for every ten pedestrians struck by a car, nine will survive when the speed at impact is 30 km/h, but only three will survive at 50 km/h, and only one will survive at 60 km/h (Bureau de prévention des accidents, 2008b). By aiming to reduce driving speeds (often to about 30 km/h), and particularly those of the fastest drivers (Transportation Demand Management [TDM] Encyclopedia, 2010a), traffic-calming strategies should help reduce the number and severity of collisions.

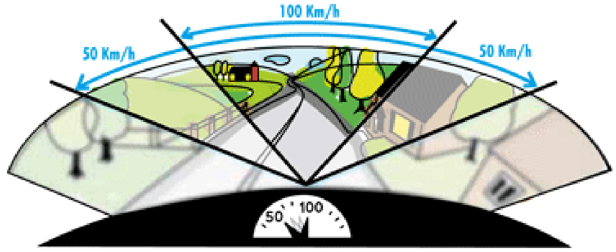

Figure 5 Narrowing of field of vision as speed increases

Source: Société de l'assurance automobile du Québec, 2011.

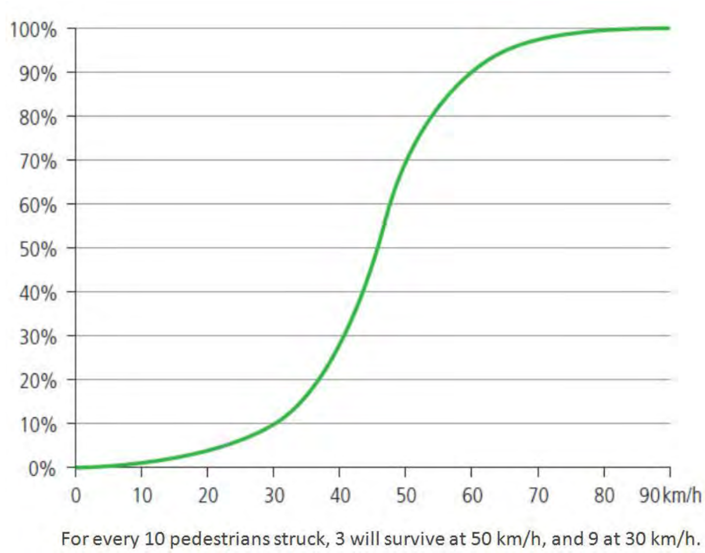

Figure 6 Probability that a pedestrian will die as a result of a collision with a car in relation to the speed at impact

Source: Adapted from Bureau de prévention des accidents, 2008b.

b) Speed homogenization

The presence of speed differentials in the traffic flow increases the probability of collisions (Ewing & Edwards, 2009; Ewing, 2000). Yet, traffic-calming strategies can cause speed differentials, for example, when drivers slow down to go over a speed hump and accelerate afterward. However, they have a tendency to more greatly reduce the speed of the fastest drivers and, thus, to reduce speed differentials in the traffic flow. The effect of a calming strategy on the number of collisions tied to speed differentials should therefore depend on the configuration of traffic-calming measures.

c) Reduction of motorized traffic volume

In general, the number of road injuries in urban settings varies according to traffic volume (Ewing, 2000). Calming strategies aimed at channelling traffic elsewhere therefore risk, all risk factors being equal, displacing collisions from one location to another instead of reducing their number. On the other hand, strategies that succeed in reducing traffic volume in absolute terms (by increasing active transportation, for example) are likely to contribute to a decrease in the number of road injuries.

d) Reduction of the number of points of conflict

Points of conflicts are locations "where the paths of two vehicles or the paths of a vehicle and a cyclist or pedestrian cross or intersect" (Ministère des Transports du Québec, 2007). As Figure 7 illustrates, some calming measures, such as roundabouts, reduce the number of points of potential conflict between public road users, which can result in a reduction in the number of collisions (Ewing, 1999).

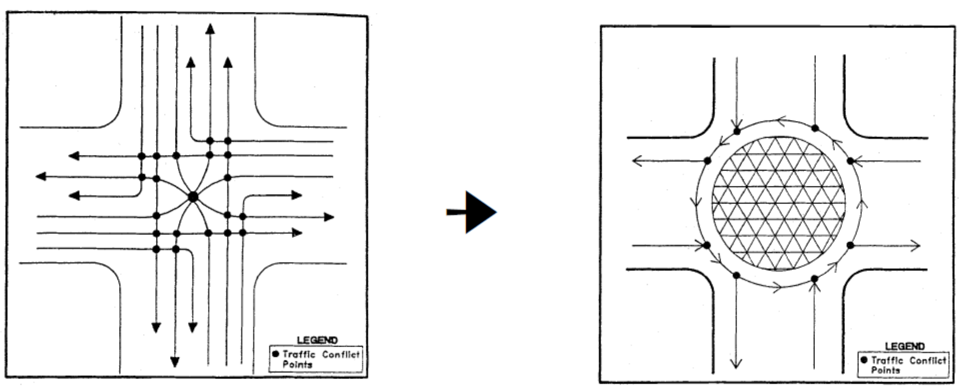

Figure 7 Number of points of conflict (black dots on the diagrams) at a traditional intersection and in a roundabout

Sources: Stein, Kittelson, Newton, & Hottmann, 1992, p. 43 in Ewing, 1999, p. 111. © 1992 and 1999 Institute of Transportation Engineers, 1627 Eye Street, NW, Suite 600, Washington, DC 20006 USA, www.ite.org. Used by permission.

e) Improvement of visibility and reduction of exposure

Certain calming measures, such as curb extensions, can improve the visibility of users (e.g., pedestrians) or reduce their exposure to the risk of collision (e.g., by reducing the distance to be travelled when crossing a street). Improving these two factors can contribute to a reduction in the number of collisions in which they play a part (Ewing & Brown, 2009).

f) Increase driver alertness

By helping create more complex environments, calming strategies can also increase driver alertness, potentially decreasing the number of collisions (Ewing, 2000).

The prevention of collisions, road injuries and deaths are among the main objectives of traffic-calming strategies, which explains why a significant portion of the existing literature is devoted to evaluating their effectiveness at doing so. In the following pages, we will first present studies that have evaluated the effects of an isolated measure installed at a specific point on the road network or of a series of isolated measures installed along a single street. We will then summarize the studies evaluating area-wide strategies.[13]

3.1.2 Effects of isolated traffic-calming measures

3.1.2.1 Objective studies

Most of the studies consulted that evaluated the effectiveness at improving road safety of isolated measures installed at specific points on the road network or on a single street simply recorded the number of collisions before and after an intervention was implemented. This method tends to systematically overestimate the effectiveness of calming measures, for which it has been severely criticized (see Box 1). These studies were systematically excluded from the literature review.

BOX 1 LIMITATIONS OF "BEFORE-AFTER" STUDIES EVALUATING THE EFFECTS OF ISOLATED INTERVENTIONS ON ROAD SAFETY

Studies with a "before-after" design evaluate the effect of interventions simply by comparing the number of collisions before and after an intervention. These studies have been criticized for not taking into account the following three confounding factors:

a) The underlying trend in the number of collisions

Studies that simply indicate the number of collisions before and after the installation of calming measures at an intervention site cannot control for an underlying trend upwards or downwards in the number of collisions. However, such trends can be caused by factors unrelated to the intervention studied, such as changes in the method for compiling data on collisions, in driving habits, in weather conditions, etc. (Persaud & Lyon, 2007).

[13] Because the improvement of perceived safety has been identified as a mechanism of action that can influence the decision of whether or not to opt for an active mode of transportation, the results of subjective studies focused on safety are not presented in this section, but in the section on "active transportation."

“Before-after” studies evaluating the effects of calming measures on road safety can thus ascribe to calming measures a level of effectiveness that they do not possess (Elvik, 1997).

b) Regression to the mean

The installation of isolated calming measures at specific points on a road network is often a response to a number or rate of collisions occurring at such spots that is judged to be abnormally high. When this is the case, we say of the calming strategy implemented that it is based on the black-spots approach, because the latter targets points on the road network where collisions, injuries or deaths are concentrated. Evaluating the effectiveness of such interventions simply by tallying the number of collisions before and after installation of the measures proves problematic, because places that register an abnormally high or low number or rate of collisions tend to regress, with time, toward an average number or rate of collisions. Studies that do not control for this statistical phenomenon, known as regression to the mean, can thus overestimate the effectiveness of calming measures (Elvik, 1997). Indeed, Mountain & Fawaz (1992) refer to one of their articles (1991) in which they recorded having observed a 62% decrease in collisions at 155 “black spots” and a 14% increase at adjacent sites, simply by monitoring the distribution of collisions over a two-year period, without any calming measure having been installed.

c) Collision migration

Following a targeted intervention, observers sometimes note what appears to be a displacement of collisions, from whence the expression “collision migration” (Joly, Bourbeau, Bergeron, & Messier, 1992). Several explanations have been proposed for this phenomenon, including regression to the mean and diversion of traffic caused by calming measures, which can, depending on the context, produce an increase in collisions elsewhere on the road network (Mountain & Fawaz, 1992). If the effects of a targeted intervention on adjacent sectors are not measured, a before-after tally of collisions at the intervention site may interpret as an improvement in safety what, in reality, is simply a migration of collisions (Elvik, 1997).

Having conducted a meta-analysis of 36 studies examining targeted measures, Elvik (1997) discovered that the reported effectiveness of interventions at reducing the number and severity of collisions was dependent on the number of confounding factors for which studies controlled. In general, studies reporting reductions in the number of collisions in the order of 50% to 90% did not control for any factors. The more factors a study controlled for, the less significant the reported effectiveness, to the point where studies that simultaneously took into account the underlying trend, regression to the mean, and collision migration did not generally report statistically significant effects.

These limitations do not exclude the possibility that interventions targeting “black spots” effectively reduce the number and severity of collisions at targeted sites. However, they point to certain difficulties related to the evaluation of interventions based on this approach and to the possible overestimation of effects reported by studies whose design is less than robust.

On the other hand, recent studies have documented significant improvements in road safety using the Empirical Bayes Method. This method makes it possible to take into account changes in traffic volume, the underlying trend in the number of collisions and the effects of regression to the mean (Persaud & Lyon, 2007). It uses data collected from control sites, the number and severity of collisions at the intervention sites before installation of the calming measures, and data concerning the evolution of traffic volumes to estimate, using regression models, the number and severity of collisions that could reasonably have been expected to occur without the installation of traffic-calming measures. The effectiveness of the intervention is then determined by comparing the number and severity of collisions having occurred since the intervention with those expected. Since we judge this method to be sufficiently reliable, three articles having used it are presented in this section. Subsequently, an article documenting an observational case-control study is also presented.

The first article (Retting, Bhagwant, Garder, & Lord, 2001) evaluated safety gains resulting from the replacement of 24 intersections controlled by stop signs or traffic lights with as many roundabouts, in the United States. Table 2 summarizes the results presented in this article.

Table 2 Effectiveness of roundabouts

Calming measure	Collisions	Personal injury collisions	Fatal and incapacitating injury collisions
Roundabout (n=24)	-38%*	-76%*	-89%*
Single-lane roundabout replacing stop signs (n=9)	-61%*	-77%*	-
Multi-lane roundabout replacing stop signs (n=6)	-5%	-	-
Single-lane roundabout replacing traffic lights (n=4)	-35%*	-74%*	-

* Significant variation at, at least, p<0.05.
Source of the data: Retting et al., 2001.

Figure 8 A single-lane roundabout

Source: http://www.flickr.com. Photographer: WSDOT.

According to the authors, reduced speeds and fewer points of conflict at roundabouts can explain the significant reduction in the number of collisions recorded and in the seriousness of those that occur. It is interesting to note that replacement of an intersection controlled by stop signs with a single-lane roundabout is particularly effective at reducing the number of collisions and injuries. Since the majority of collisions occur at intersections, the article concludes that replacing intersections controlled by traffic lights or stop signs with roundabouts, where conditions permit, has considerable potential for reducing collisions, but above all for reducing injuries and deaths.

An article (Stout, Pawlovich, Souleyrette, & Carriquiry, 2006) evaluates the impact of 15 road diets in the United States, using the Empirical Bayes Method (23 years of data) and a “before-after” design with control sites (10 years of data). This calming measure usually consists of converting four-lane roads into three-lane roads, with one lane for traffic going in each direction and a central lane reserved for left turns from either direction. As shown in Figure 9, the public space recovered when road diets are implemented can be used to install bike lanes and sidewalks or to green streets.

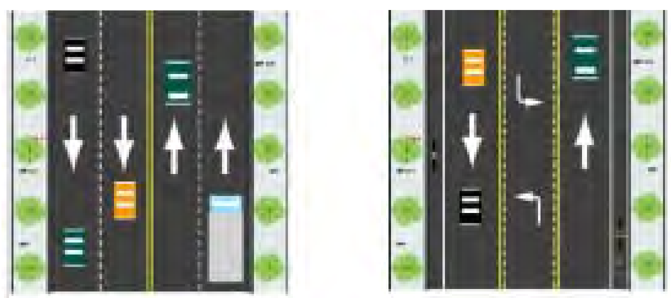

Figure 9 Before (left) and after (right) a road diet

Source: Rosales, 2007, p. 2.

Table 3 summarizes the results presented in this article.

Table 3 Effectiveness of road diets

Calming measure	**Method of evaluation**	**Collisions per kilometre** (collision density)	**Collision rates** (controlled for variations in volume)	**Total personal injury collisions**	**Minor injury collisions**	**Fatal and serious collisions**
Road diet	Bayes	-25%	-19%	-	-	-
	“Before-after” with control sites	-29%	-21%	-34%	-30%	-11%

Note: No statistical significance test mentioned.
Source of the data: Stout et al., 2006.

The article concludes that road diets can be used to reduce the number of collisions, injuries and deaths, but the authors do not indicate whether these reductions are statistically significant.

An article (Mountain, Hirst, & Maher, 2005) compares the effectiveness of 149 traffic-calming interventions on roads with 48-km/h (30-mph) speed limits located throughout England. These interventions were classified into three groups: the 79 interventions using speed cameras, the 39 using vertical deflections (alone or combined with horizontal deflections or road narrowings) and the 31 interventions using only horizontal deflections, narrowings, speed activated signs (n=4) or markings indicating the speed limit (n=1). The final unusual grouping is justified, according to the authors, by the similarity of the associated results. Table 4 summarizes the key results presented in this article.

Table 4 Comparison of the effectiveness of three types of calming measures

Calming measures	**Average speed** {CI 95%}	**Personal injury collisions** {CI 95%}	**Fatal and serious collisions** {CI 95%}	**Number of personal injury collisions avoided (collision/km/year)** {CI 95%}
Vertical deflections	-13.5 km/h* {-16.6 to -10.5}	-44%* {-54 to -34}	-35%* {-54 to -18}	-1.00* {-1.4 to -0.6}
Horizontal deflections or narrowings	-5.3 km/h* {-7.1 to -3.7}	-29%* {-48 to -8}	-14% {-44 to +32}	-0.78* {-1.6 to -0.2}
Speed cameras	-6.6 km/h* {-7.6 to -5.5}	-22%* {-30 to -13}	-11% {-26 to +6}	-1.03* {-1.4 to -0.8}

* Significant variation at, at least, $p < 0.05$.
Source of the data: Mountain et al., 2005.

Traditionally, the effectiveness of interventions is expressed in terms of a percentage reduction in the various types of collisions. Presented thus, interventions making use of vertical deflections are significantly more effective at reducing personal injury collisions than those making use of speed cameras. This result seems to correspond to the significantly more pronounced effect of vertical deflections on speed. However, if the effectiveness of interventions is expressed in terms of the number of personal injury collisions avoided, the significant effectiveness of the three types of calming measures is similar. The authors attempt to explain the variation in the results associated with these two perspectives by pointing to differences in implementation contexts. The speed cameras referred to in this article were installed, for example, on streets with high traffic flow and at sites where more personal injury collisions were recorded (almost double the collisions before the interventions) than at sites where vertical deflections were installed, usually on local streets with lower traffic flow. Thus, in addition to demonstrating the overall effectiveness of traffic-calming measures at significantly reducing the number of collisions and personal injury collisions, the article underlines the importance of taking into account implementation contexts when comparing the effectiveness of different measures.

An article (Tester, Rutherford, Wald, & Rutherford, 2004) presenting an observational case-control study evaluates the effectiveness of speed humps at reducing collisions causing death and injury among child pedestrians under 15 years old in the city of Oakland, in the United States. The article analyzes the admission data of hospital emergency departments over a period of five years (1995-2000) to identify children living on local streets who were admitted after being struck by a car while walking near their home (radius of 0.4 km). The article excludes collisions caused by cars backing out of a driveway or a parking space. Each of the one hundred children whose situation satisfied the selection criteria was matched with two control children admitted on the same day to the emergency department for other reasons, but matched in terms of gender and age and also living on a local street. The three hundred children were classified into two categories: those living on a street block with at least one speed hump and those living on a street block without any speed humps. Among the control children, 23% (n=46) lived near a speed hump, whereas among case children, the rate goes down to 14% (n=14). The matched-pairs analysis indicates that the probability of a child living near a speed hump being injured by a car near home (radius of 0.4 km) and admitted to hospital is significantly lower (OR[14]: 0.50, CI 95%: 0.27 to 0.89) than for a child not living near this type of calming measure. When the analysis considers only those children injured on the street block where they live (n=49), the protective effect of speed humps is even greater (OR: 0.38, CI 95%: 0.15 to 0.90). Controlling for race and ethnicity, the protection provided by proximity to a speed hump remains statistically significant and similar for children injured within a radius of 0.4 km (OR: 0.47, CI 95%: 0.24 to 0.95); however, although the point estimate still indicates a protective effect, this is no longer statistically significant for children injured on the street block where they live (OR: 0.40, CI 95%: 0.15 to 1.06). On the basis of these results, the article concludes that speed humps make the environment safer for child pedestrians.

3.1.2.2 Summary of the results for isolated traffic-calming measures

The documentary search led to the selection of four articles (Retting et al., 2001; Stout et al., 2006; Mountain et al., 2005; Tester et al., 2004) belonging to the scientific literature having evaluated the effectiveness of various calming measures (roundabouts, road diets, vertical deflections, horizontal deflections or narrowings, and speed cameras) at reducing the number of collisions, injuries and deaths. The authors of three articles used the Empirical Bayes Method, whereas one article presents a “case-control” study. The results were not all tested for statistical significance, but the majority of the results for which tests are known to have been carried out were significant. The key points to recall are the following:

[14] OR or odds ratio: An odds ratio is a statistic produced through logistic regression that expresses the relationship between the probability that an event will occur and the probability that it will not occur. An odds ratio can be used to determine if, all other things being equal, persons living in an environment defined by certain characteristics are more or less likely to move around by bicycle, for example. An odds ratio of 1 would indicate that the characteristic had no effect, whereas a ratio of less than 1 would indicate that the characteristic in question lowers the likelihood that such persons would move around by bicycle and a ratio of more than 1 would indicate an increase in the likelihood. The further the odds ratio is from 1, the greater the effect on the probability of the event occurring.

a) Reduction in collisions, injuries and deaths

All of the articles report a reduction in collisions, injuries and deaths tied to the presence of the calming measures evaluated.

b) Speeding, collisions, injuries and deaths

One article (Mountain et al., 2005) supports the assumption in the logic model of a relationship between a reduction in vehicle speeds and a reduction in collisions, injuries and deaths.

c) Promising calming measures

Among the calming measures evaluated, single-lane roundabouts (Retting et al., 2001) and vertical deflections (Mountain et al., 2005), such as speed humps (Tester et al., 2004), were shown to be particularly effective at reducing collisions, injuries and deaths.

3.1.3 Effects of area-wide calming schemes

3.1.3.1 Objective studies

BOX 2 THEORETICAL ADVANTAGES OF AREA-WIDE STRATEGIES OVER ISOLATED INTERVENTIONS FOR IMPROVING ROAD SAFETY IN URBAN SETTINGS

With regard to reducing the number and severity of collisions in urban settings, it is reasonable to assume that area-wide traffic-calming strategies have, in theory, three main advantages over strategies that intervene at specific points or on specific segments of the road network:

a) Collision dispersion

To begin with, as illustrated in Figure 10, collisions in urban settings are generally dispersed throughout the road network occurring at a multitude of points each registering a relatively small number of collisions. Given this context, a classic black-spots approach does indeed make it possible to identify the places where a greater number of collisions or injuries occur and to take action there, but an area-wide approach offers the potential advantage of decreasing the risk of collision or injury at a greater number of sites, and thus at a significant proportion of potential collision sites within an area or neighbourhood. For example, the article by Morency & Cloutier (2006) identifies 22 “black spots” for pedestrians on the island of Montréal, with “black spots” being arbitrarily defined as places where at least eight pedestrians were injured during a five-year period. However, these “black spots” represent only 4% of the pedestrians injured during this period, whereas 5082 pedestrians were injured at over 3500 different sites.

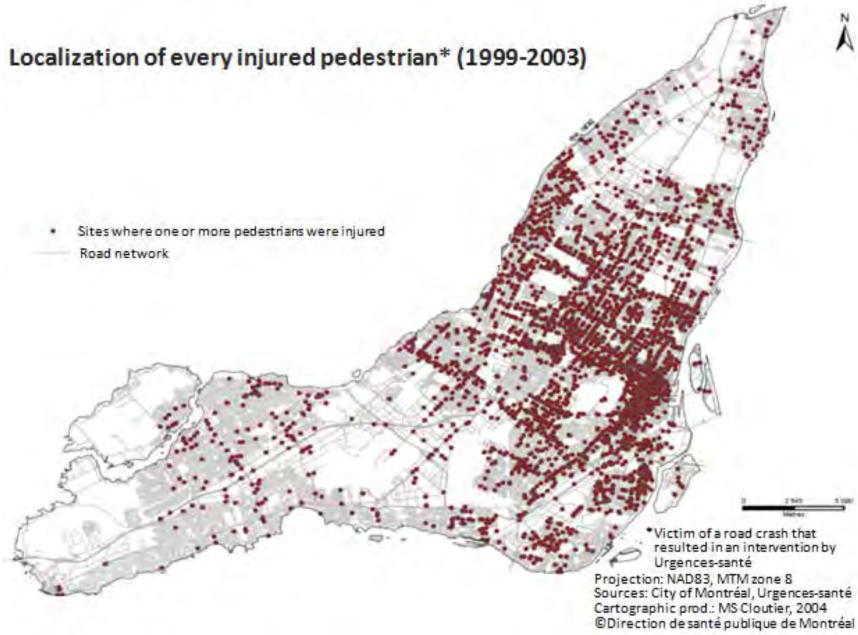

Figure 10 An example of collision dispersion in an urban setting

Each point on this map of the island of Montréal indicates a spot where an ambulance was sent during the 1999-2003 period for a pedestrian injured by a motor vehicle.

Source: Adapted from Morency & Cloutier, 2005, p. 31.

b) Collision migration

If drivers use adjacent residential streets to avoid points on the road network that have been calmed, a targeted approach that intervenes at "black spots" is likely to displace collisions elsewhere. To prevent this migration of collisions, the area-wide approach often explicitly attempts to manage diverted traffic by channelling it toward roads that are better adapted to higher speeds and volumes and by ensuring the safety of the latter, notably, through the use of appropriate calming measures (e.g., curb extensions, roundabouts, speed tables, etc.).

c) Volume reduction

Whereas targeted interventions installed at "black spots" generally seek to reduce speeds at specific points on the road network to improve safety at those points, an area-wide approach typically seeks to reduce traffic volumes, as well as speeds, throughout an area. Such reductions in volume can result not only from efforts to channel a portion of traffic (through traffic) onto roads that are better designed to receive it, but also from interventions that encourage the adoption of alternate means of travel and, in particular, of active and public transportation. In theory, the area-wide approach may thus have an advantage over the black-spots approach, in that it seeks not only to reduce vehicle speeds, but also to reduce the number of trips made in automobiles in a given area.

Elvik (2001) published a systematic review with meta-analysis focused on 33 studies evaluating the effectiveness of area-wide strategies at reducing the number of collisions with and without injuries. No studies were excluded on the basis of the methodology used. Table 5 presents the significant results of the meta-analysis, when these include the data reported by the 33 studies examined:

Table 5 Effectiveness of area-wide strategies according to collision site

Calming strategy	Collision site	Collisions without injury {CI 95%}	Personal injury collisions {CI 95%}
Area-wide strategies	Local streets	-29%* {-25 to -22}	-24%* {-29 to -18}
	Main roads	-11%* {-16 to -6}	-8%* {-12 to -5}
	Entire area	-16%* {-19 to -13}	-15%* {-17 to -12}

* Significant variation at, at least, $p < 0.05$.

Source of the data: Elvik, 2001.

The article concludes that there were significant reductions in collisions with and without injury on local streets and main roads, as well as throughout the area. The reductions observed on local streets were significantly greater than those on main roads. However, when retaining only the studies with the most robust designs ("before-after" with control sites) for the purpose of evaluating the effect on personal injury collisions, only the reduction of 12% (CI 95%: -21 to -1) for the entire calmed area remains statistically significant. The studies were grouped by decade of publication and by country to allow for verification of the external validity of the results. These results were relatively consistent across decades and countries, so the reported effectiveness does not seem to be the result of confounding factors, as these would have had to influence results in a consistent and uniform manner across the varying implementation and evaluation contexts.

Another systematic review with meta-analysis, first published in 2003, then updated in 2009, was carried out by Bunn et al*.* (2003; 2009). The first version of this review synthesizes the results of 12 studies examining 16 area-wide strategies, and the second version synthesizes the results of 18 studies examining 22 area-wide strategies, implemented in high-income countries. Having searched systematically for studies using "before-after" designs with control sites or randomized trials, the authors found only "before-after" studies with control sites. Table 6 presents the results of both versions of the meta-analysis.

Table 6 Effectiveness of area-wide strategies

Version	Collisions {CI 95%}	Collisions involving a pedestrian {CI 95%}	Personal injury collisions (including death) {CI 95%}	Fatal collisions {CI 95%}
2003	-5% {-19 to +11}	0% {-16 to +18}	-11% {-20 to 0}	-37% {-86 to +159}
2009	-11% {-24 to +5}	+1% {-12 to +16}	-15%* {-25 to -4}	-21% {-77 to +168}

* Significant variation at, at least, $p < 0.05$.

Sources of the data: Bunn et al., 2003; 2009.

Despite these generally positive results, only the reduction in personal injury collisions from the 2009 analysis is statistically significant. This significant reduction (-15%) corresponds to the significant reduction in personal injury collisions for calmed areas reported in the meta-analysis by Elvik (2001). It should be noted that the diverse range of calming schemes included in the literature review (going from a scheme using only stop signs to schemes using a wide variety of engineering measures) may obscure the superior effectiveness of some types of schemes.

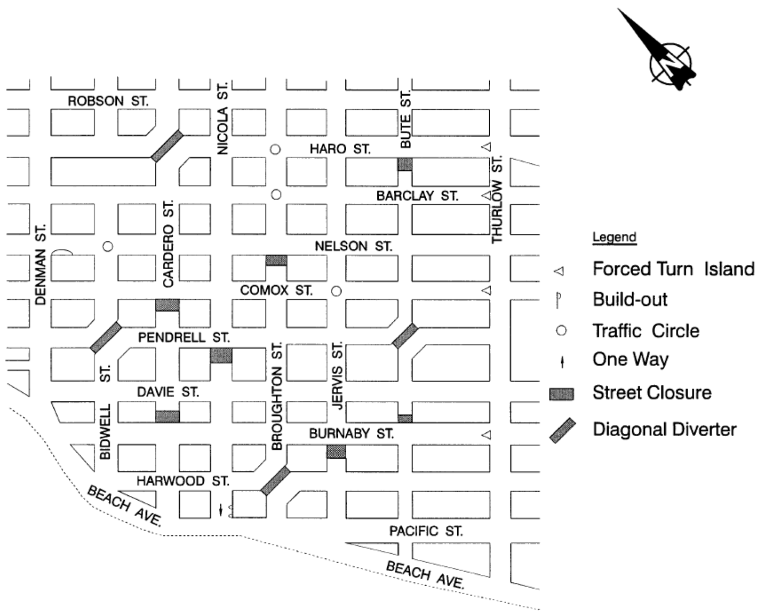

Figure 11 City of Vancouver West-End neighbourhood traffic-calming scheme

Source: Zein et al., 1997, Figure 1, p. 4. Copyright, National Academy of Sciences, Washington, D.C., 1997. Reproduced with permission of the Transportation Research Board.

An article (Zein, Geddes, Hemsing, & Johnson, 1997) evaluates four area-wide schemes implemented in the Greater Vancouver region, in Canada, including one in the West-End neighbourhood of downtown Vancouver, which is illustrated in Figure 11. As an indicator of the severity of collisions, the value of insurance claims linked to collisions before and after the interventions was compared.[15] The data used cover a period of one year prior to the interventions, but no details are provided concerning the data collected after the interventions. Neither the methodology nor the data used to arrive at the results are presented in the document. Moreover, no statistical significance test is mentioned. The results should therefore be interpreted with caution.

[15] "Before-after" type studies evaluating the effects of area-wide interventions on collisions, injuries and deaths are not as subject to bias as those evaluating black-spots interventions. That is why we have included the former and excluded the latter. In specific terms, because area-wide interventions are not implemented at specific points where there is a high risk of collisions, their evaluations are less prone to the effects of regression to the mean. Moreover, since they typically aim at directing diverted traffic toward the appropriate roads and at making these safe, they are less likely to result in collision migration–which the studies of Grundy et al. appear to confirm (2008a; 2008b; 2009). However, "before-after" studies are just as likely to mistake a general downward trend in the number of collisions, injuries and deaths for the effect of interventions, regardless of whether these are area-wide or isolated.

The article concludes that an average reduction in collisions of 40% occurred, with substantial variations between areas (-18% to -60%), and that the average reduction in the value of claims was 38% (-10% to -57%).

In 1999, the Transport Research Laboratory published a report (Cloke et al., 1999) evaluating the effects of an area-wide scheme, implemented in the Leigh Park area of Havant, England, comprising various calming measures (raised intersections, pedestrian refuges, curb extensions, raised pedestrian crossings, speed cushions, raised medians, mini-roundabouts and gateways). The schematic plan of this intervention is included in section 3.2.3.1. Among the effects evaluated was the impact on the number of collisions and personal injury collisions, with occurrences before (3 years) and after (20 months) the intervention being compared. Because the data collection periods were judged to be too short, the authors presented the results without carrying out statistical significance tests. While these results should be interpreted with caution, it is interesting to note that the number of collisions per year in the area remained similar, along with the number of personal injury collisions involving motorcyclists, cyclists or adult pedestrians, whereas the number of personal injury collisions involving child pedestrians decreased by 50% per year.

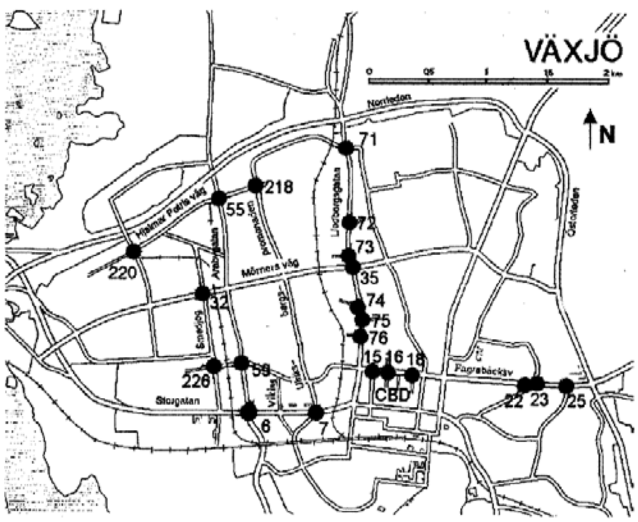

Figure 12 Scheme involving installation of 21 mini-roundabouts in Växjö, Sweden

Source: Hyden & Várhelyi, 2000, p. 12.

The article by Hyden & Várhelyi (2000) evaluates the effect on road safety of a scheme involving the installation of 21 mini-roundabouts in Växjö, Sweden (see Figure 12), at intersections with daily traffic volumes of up to 23,500 vehicles. The scheme replaced one intersection controlled by traffic lights and 20 intersections without signals with mini-roundabouts. An indirect measurement of road safety was obtained using the conflicts technique, which made it possible to estimate the number and type of collisions before and after implementation of the scheme based on the conflicts observed between the various road users. Thus, twelve intersections affected by the changes were observed for thirty hours each (the article does not specify how these hours were divided between the periods before and after the changes). Table 7 presents the estimates based on these observations.

Table 7 Estimated effectiveness based on the conflicts technique of a mini-roundabout scheme

Calming strategy	Personal injury collisions	Collisions with injured driver	Collisions with injured pedestrian	Collisions with injured cyclist
Scheme involving 21 mini-roundabouts	-44%	+12%	-80%	-60%

Note: No statistical significance test mentioned.
Source of the data: Hyden & Várhelyi, 2000.

According to the authors, the estimated increase in the number of drivers injured can be partly explained by a poorly-designed mini-roundabout where the risk of personal injury collision increased by approximately 200%. The authors conclude that, if this mini-roundabout with a defective design is excluded, the mini-roundabout scheme can be seen to have led to a “very significant” reduction in risk for vulnerable users (pedestrians and cyclists) without either increasing or decreasing the risk for drivers and passengers, but no statistical analysis is presented in support of this claim.

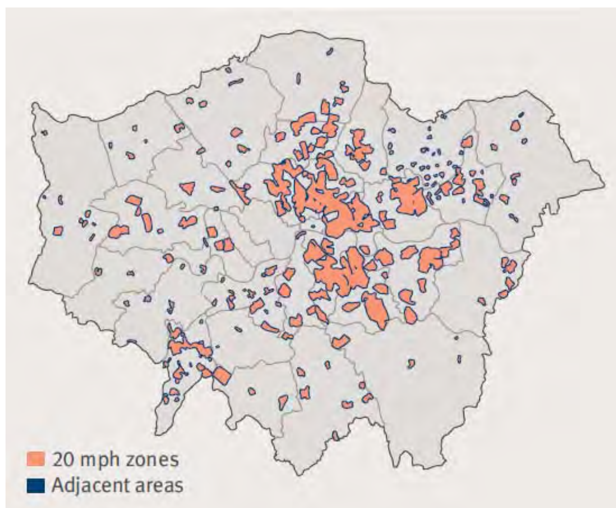

Figure 13 20-mph zones and adjacent areas in London, U.K.

Source: Grundy et al., 2009, p. 2.

A report (Grundy, Steinbach, Edwards, Wilkinson, & Green, 2008b), as well as a more synthetic article in a scientific journal (Grundy et al., 2009), examine the 399 zones with 20-mph (32-km/h) speed limits that have been installed in London, U.K., gradually since 1990 (see Figure 13). They evaluated the effects of these zones on collisions, injuries and deaths occurring within the zones and on their periphery. Typically, the entrance to and exit from the zones are marked with signs, and traffic within the zones is calmed, in particular, through the use of vertical deflections (e.g., raised intersections) and horizontal deflections (e.g., chicanes). The size of calmed zones ranges from a 0.07-km stretch of road to an area covering 37 km of roads, with a median size of 3.6 km. The authors used collision data collected by the police department over a period of twenty years (1986-2006) to calculate the effect of the zones on the roads within them and to verify whether collisions had migrated to adjacent roads (within 150 m). The data was also used to control for the phenomenon of regression to the mean and for the underlying downward trend in the number of collisions occurring in London. According to the results presented, the 20-mph zones are responsible for a significant reduction in the number of collisions; specifically, a reduction of 37.5% (CI 95%: -31.6 to -43.4), with no indication of collision migration. In fact, even after controlling for the underlying downward trend, a significant reduction in collisions of 7.4% (CI 95%: -3.8 to -11.0) was observed on the periphery of the calmed zones. This reduction cannot, however, be explained with reference to the article. The authors speculate that it may be due to the proximity of the 20-mph zones or to other interventions on these roads (e.g., speed cameras on the main roads bordering the zones). Table 8 presents the key results concerning the number of road injuries by category of user.

Table 8 Effectiveness of 20-mph (32-km/h) zones at reducing personal injury collisions occurring within them

	Pedestrians {CI 95%}	**Cyclists** {CI 95%}	**Drivers or passengers** {CI 95%}	**Motorcyclists** {CI 95%}	**Total** {CI 95%}
Personal injury collisions (PICs)	-32.4%* {-37.7 to -27.1}	-16.9%* {-29.0 to -4.8}	-52.5%* {-62.4 to -42.5}	-32.6%* {-43.4 to -21.7}	-41.9%* {-47.8 to -36.0}
0-15 years	-46.2%* {-55.5 to -36.8}	-27.7%* {-49.1 to -6.3}	-	-	-48.5%* {-55.0 to -41.9}
Collisions with persons killed or seriously injured (KSI)	-34.8%* {-47.5 to -22.18}	-37.6%* {-60.9 to -14.4}	-61.8%* {-71.7 to -52.0}	-39.1%* {-59.1 to -19.0}	-46.3%* {-54.1 to -38.6}
0-15 years	-43.9%* {-61.3 to -26.6}	-	-	-	-50.2%* {-63.2 to -37.2}

* Significant variation at, at least, $p < 0.05$.
Sources of the data: Grundy et al., 2008b; 2009.

These results show that the 20-mph zones significantly reduced the number of personal injury collisions (PICs) and of collisions with persons killed or seriously injured (KSI) for the various groups of public road users. The point estimates suggest that the 20-mph zones are particularly effective at protecting children (0-15 years old), but in the absence of data applying solely to adults, it is impossible to determine whether these differences are statistically significant. A comparison of the measure's effectiveness at reducing PICs and KSI collisions in large zones (more than 3.6 km of road) and in small zones (3.6 km and less) revealed no significant difference. On the basis of the most moderate risk reduction factor, Grundy et al. (2009) estimated that the 399 20-mph zones in London prevent 203 persons, including 51 pedestrians from being injured each year, and that, of these, 27 would have been seriously injured or killed.

In another report, Grundy et al. (2008a) evaluate the effects of the same 399 20-mph zones on inequalities in road injuries among five levels of socioeconomic status (SES) and four racial categories. The locations where the collisions occurred were classified into five SES quintiles based on the *Index of Multiple Deprivation 2004*, using 2001 census data and police data from 1987 to 2006. Those injured in road collisions were grouped into four racial categories (white, Asian, black and other)[16] using police data from 1996 to 2006.

Effects according to socioeconomic status

Based on the classification of areas into quintiles, the authors determined that in 2000 the percentage of road kilometres covered by 20-mph zones was less than 2%, regardless of SES quintile. By 2008, the situation had substantially changed in favour of the most deprived persons. In fact, the more deprived an area, the higher this percentage rose. The percentage of roads covered was 2.5% for Q1 (the least deprived quintile), 5.9% for Q2, 9.7% for Q3, 17.7% for Q4, and 27.5% for Q5 (the most deprived quintile). Between 1987 and 2006, the effectiveness[17] of 20-mph zones at reducing annual amounts of personal injury collisions (PICs) and collisions with person killed or seriously injured (KSI) on roads covered by the zones and on adjacent roads (within 150 metres) did not vary significantly according to the SES quintile where zones were implemented. However, there were two exceptions: the reduction in PICs involving motorcyclists and the reduction in PICs involving car occupants were significantly higher on roads adjacent to 20-mph zones implemented in the most deprived areas than on roads adjacent to zones implemented in the least deprived areas. Despite the fact that the majority of 20-mph zones were implemented in areas with a low SES, annual aggregate reductions across London, between 1987 and 2006, were significantly greater in the quintiles with the highest SES, as regards total PICs and collisions involving children, pedestrians, cyclists, motorcyclists and car occupants.

Effects according to racial categories

Between 1996 and 2006, on roads adjacent to 20-mph zones, annual reductions in PICs and KSI collisions did not vary significantly among people identified as white, black and Asian. However, in 20-mph zones, annual reductions were significantly lower for black people than for white or Asian people, as regards total KSI collisions and PICs involving pedestrians and child pedestrians. The report does not provide an explanation for these differences, but the authors speculate that they may be the result of a proportionately and progressively greater exposure of black people to the risk of collision, in particular because they would have walked more than white or Asian people. Between 1996 and 2006, annual reductions were also significantly greater for white people than for Asian or black people, as regards total KSI collisions, total PICs and PICs involving children, pedestrians, child pedestrians, cyclists, motorcyclists and car occupants.

[16] The researchers used the terms “Black,” “White,” “Asian,” and “Other” to group together “police-assigned ‘ethnicity’ code from the STATS19” (Grundy et al., 2008a, p. 10), the form used by London's police to report collisions. While the authors of the present document have reservations about the use of these particular terms, neither do we wish to ignore the evidence that inequalities exist along the line of long-standing categories related to perceptions of race. With this proviso, we will repeat them as such.

[17] As is standard practice in the literature, effectiveness is here expressed as a percentage reduction in personal injury collisions and fatal or serious injury collisions, and not in terms of the number of injuries, serious injuries and deaths avoided. This practice is not without consequence for the results, for there are often more collisions, injuries and deaths in deprived areas than in the least deprived areas (Laflamme et al., 2010; Cubbin & Smith, 2002; Morency & Cloutier, 2005). Thus, it is likely that interventions whose effectiveness, expressed as a percentage, is the same for areas with different SES would prevent more collisions, injuries and deaths if they were implemented in areas with a lower SES.

These results led the authors to conclude that inequalities in road injuries have increased in London despite the more intensive implementation of 20-mph zones in the most deprived areas. On the basis of a less moderate risk reduction factor than that used in 2009 (Grundy et al., 2009), the authors conclude that by targeting deprived areas for the implementation of 20-mph zones, 1193 personal injuries were prevented each year, with almost half of these being in the most deprived quintile. Based on the number of injuries avoided, 20-mph zones can thus be seen to have reduced the widening of the gap between the least deprived and the most deprived quintiles by about 15%. It should be noted that this result was not accompanied by a statistical significance test.

Another article (Jones et al., 2005), focused on two similar cities in England, also evaluates the potential of traffic-calming measures for reducing inequalities in road injuries, but in this case the focus is limited to child pedestrians (4-16 years old) injured following a collision in areas with varying levels of socioeconomic status (SES). The two cities were divided into areas classified according to four levels of SES. An audit was carried out of the calming measures installed in the two cities, but this audit was limited to speed humps, road narrowings, and road closures. In city A, the areas in the most deprived fourth had 4.80 (CI 95%: 3.71 to 6.22) times more calming measures per 1000 residents than those in the least deprived fourth; that is, a significantly greater ratio between these two fourths than that of city B (1.88 [CI 95%: 1.46 to 2.42]). Rates of personal injury collisions per 1000 residents were compared for the cities and for areas. In the absence of precise information about the dates when the calming measures were installed, the periods of 1992-1994 and 1998-2000 were compared, municipal authorities in both cities having indicated that installation of the measures occurred mainly from the mid 1990s onwards. The analyses took into account the number of children in both cities, the number of families with a car and the number of children walking to school. It should be noted that, although the evaluation considers the effect of calming measures on an area comprising more than one road, the article does not indicate whether the measures installed on these roads were planned and implemented so as to function in a systemic manner (area-wide approach) or resulted from an accumulation of individual measures installed at specific points over time (black-spots approach). Table 9 summarizes the results presented in this article.

Table 9 Effects of the number and distribution of calming measures on inequalities in road injuries among child pedestrians

	Child pedestrian (4-16 years old) injury rate (‰)			**Gap between the rates (‰) of the least and most deprived fourths**	
	1992-1994	**1998-2000**	**Difference** {CI 95%}	**1992-1994** {CI 95%}	**1998-2000** {CI 95%}
City A	6.98	4.84	-2.14* {-2.81 to -1.48}	3.21* {2.27 to 4.54}	2.01* {1.45 to 2.87}
Most deprived areas	9.53	5.85	-3.68* {-5.28 to -2.13}		
City B	6.05	5.25	-0.80 {-1.88 to 0.27}	4.27* {2.51 to 7.28}	3.96* {2.26 to 6.95}
Most deprived areas	8.99	7.67	-1.32 {-3.62 to 0.97}		

* Significant variation or difference of at least, $p < 0.05$.

Source of the data: Jones et al., 2005.

These results led to the observation that in city A, where a greater number of calming measures were installed (city A: 891/city B: 553), the child pedestrian injury rates decreased significantly throughout the city and in the most deprived areas. As for city B, the point estimates indicate reductions, but these are not statistically significant. Based on the point estimates, the reduction in the gap between the injury rates of the least and most deprived areas seems greater for city A, where a greater proportion of measures were installed in the most deprived areas (city A: 4.80/city B: 1.88). However, neither of the gap reductions is statistically significant, nor, moreover, is the gap between the rates of the two cities. Nevertheless, the results of the article indicate that variations in the child pedestrian injury rate are inversely correlated (r=-0.769, p=0.026) with the density of traffic-calming measures in an area, that is, to the number of calming measures per kilometre of road. Thus, the article supports the conclusion that the more numerous traffic-calming interventions in city A are associated with a significant reduction in collisions involving injured child pedestrians, but it does not support the conclusion that having targeted the most deprived areas led to a significant reduction in inequalities. Ultimately, even though the authors of the article were unable to measure such an effect, increasing the density of calming measures in deprived areas would likely help reduce inequalities.

3.1.3.2 Summary of the results for area-wide calming schemes

The documentary search led to the identification of three systematic reviews with meta-analyses (Elvik, 2001; Bunn et al., 2003; 2009) (including one revised update) and three other articles (Zein et al., 1997; Grundy et al., 2009; Jones et al., 2005) belonging to the scientific literature, as well as four studies (Cloke et al., 1999; Hyden & Várhelyi, 2000; Grundy et al., 2008a; 2008b) drawn from the grey literature. These studies evaluate the effectiveness of various area-wide schemes at reducing collisions, injuries and deaths, as well as their unequal distribution within the population.

They use different methodological approaches and are not all equally rigorous, but they generally arrive at results which converge and which agree with the main mechanisms of action recognized. The key points to recall are the following:

a) Reduction of collisions, injuries and deaths

Two of the three meta-analyses report significant reductions of 15% in personal injury collisions (Bunn et al., 2009; Elvik, 2001), while the third reports reductions, but not significant ones (Bunn et al., 2003). With regard to the studies examining specific area-wide interventions, these all report overall reductions in collisions, personal injury collisions, and collisions causing serious injury or death. Of these latter studies, all those whose results are accompanied by statistical significance tests report significant reductions (Grundy et al., 2008b; 2009; Jones et al., 2005).

b) Protection of the most vulnerable road users

Neither of the meta-analyses that focused on the effects on pedestrians notes any effect on this category of user (Bunn et al., 2003; 2009). However, the other studies that focus on vulnerable users report significant reductions in collisions involving pedestrians, cyclists and motorcyclists (Grundy et al., 2008b; 2009; Jones et al., 2005) or report reductions without mention of statistical significance tests (Hyden & Várhelyi, 2000). Three studies also point out that more marked reductions were observed among children walking or cycling than among adults using these same modes of travel (Grundy et al., 2008b; 2009; Hyden & Várhelyi, 2000).

c) Reduction of inequalities

One of the studies controlling for several confounding factors (Grundy et al., 2008a) concludes that the effectiveness (expressed as a percentage) of 20-mph zones at reducing personal injury collisions did not vary according to the socioeconomic status of the area in which they were implemented, but that they tended to protect people identified as black less than those identified as white or Asian. This study and an article that controlled for fewer factors (Jones et al., 2005) evaluate whether having targeted deprived areas for the implementation of area-wide schemes led to a reduction in inequalities. One (Jones et al., 2005) reports a non-significant reduction in inequalities and the other (Grundy et al., 2008a) reports a reduction in the growth of inequalities, but without accompanying this result with statistical significance tests.

d) Collision migration

Notwithstanding the fact that area-wide strategies generally seek to redirect some of the traffic using an area's residential streets toward the main arteries of a road network, one meta-analysis (Elvik, 2001) and one of the more recent articles (Grundy et al., 2009) indicate that not only do collisions not migrate with the redirected traffic, but also that their number decreases significantly on these arteries (Elvik, 2001; Grundy et al., 2009). However, the articles do not explain these results.

e) Promising area-wide strategies

The studies consulted do not allow for a comparison of the effectiveness of the various area-wide strategies evaluated. However, one article (Jones et al., 2005) indicates that the density of calming measures (no. of measures/km) is significant, because it was inversely correlated to the rate of child pedestrians injured. Another study (Grundy et al., 2008b) suggests that the size of calmed areas does not affect the effectiveness of area-wide strategies at reducing personal injury collisions and collisions causing serious injury or death.

3.1.4 Conclusion of the section on the number and seriousness of collisions

3.1.4.1 Section summary

Traffic-calming interventions are mainly promoted as a way of reducing the number of collisions, injuries and deaths. Despite the range of traffic-calming measures and strategies evaluated, the studies consulted lead to the conclusion that, in general, traffic calming effectively helps improve road safety. This conclusion is based on several studies whose methodologies and levels of rigorousness vary and whose results converge and, generally, agree with the mechanisms of action identified. The studies show that interventions targeting locations where the risk of collisions and injuries is high (black-spots approach) as well as area-wide strategies can substantially reduce collisions, injuries and deaths. Thus, it is difficult to draw conclusions about the advantages and disadvantages of individual interventions relative to area-wide interventions, especially since the significance of gains in both cases likely derives from the intensity, the extent and the context of interventions, regardless of the approach used.

3.1.4.2 Research gaps

Comparison of approaches

It would be relevant for studies to seek to compare the effectiveness at reducing collisions, injuries and deaths of calming strategies based on the black-spots approach and strategies arising from the area-wide approach. A city such as Montréal, where the two types of strategies are currently being developed in different boroughs, offers a very interesting opportunity to compare the two approaches.

Traffic diversion

The area-wide approach rests partly on the hypothesis that the diversion of motorized traffic away from local residential streets and onto the main road network (arteries, highways) will not simply displace collisions from one place to another, but will rather decrease their number or seriousness. However, the risk of collision and injury on arteries, in particular, is generally high (Dumbaugh & Rae, 2009; Lovegrove & Sayed, 2006). While two articles (Elvik, 2001; Grundy et al., 2009) report that the area-wide strategies evaluated did not cause collisions to migrate from local streets to arteries, neither of these articles took into account in their analyses the possible presence of measures aimed at adapting these roads to accommodate an increase in volume or at enhancing their safety, for example, through the use of calming measures adapted to this type of road (e.g., roundabouts, curb extensions, speed tables, etc.). Research would be required to determine the conditions under which diverting traffic through area-wide strategies would not cause collisions to migrate to the main road network.

Figure 14 Speed table: a measure designed for faster lanes and heavy vehicles

Source: Boulter et al., 2001, p. 11.

Inequalities

In a similar vein, if it is possible that some interventions which redirect a certain amount of traffic from local streets onto arteries increase road safety problems on those arteries, then, given that persons with low socioeconomic status tend to be overrepresented as residents of these roads (Smargiassi, Berrada, Fortier, & Kosatsky, 2006), it would be relevant for researchers to examine the potential effects of such redirection on inequalities in road injuries and deaths.

3.2 AIR QUALITY

In urban environments, traffic is responsible for a significant portion of emissions of nitrogen oxides (NO_x), carbon monoxides (CO), volatile organic compounds (VOCs)–including hydrocarbons (HC), and particulate matter (PM). As an example, in Toronto, motor vehicles are responsible for 85% of CO, 69% of NO_x and 16% of $PM_{2.5}$ (Toronto Public Health, 2007). The air pollution to which these emissions contribute has been associated with increases in the incidence and in the prevalence of certain health problems, such as premature death, cardiovascular and respiratory diseases, cancers, etc. (Toronto Public Health, 2007). It is important to distinguish between the emission of air pollutants and their effects on air quality, because a variation in emissions does not necessarily produce a linear variation in ambient air quality. In reality, the relationship between the two is mediated by, for example, ambient temperature, prevailing winds, the presence of other reactive molecules or other emission sources, etc. This said, various actions can be taken to reduce traffic emissions or the effects of these emissions on the quality of the air to which populations are exposed. For example, technology can reduce vehicle emissions (e.g., catalytic converters), and urban planning and the planning of transportation networks can reduce traffic volumes (e.g., densification, public transportation) or move traffic away from residential areas (e.g., urban bypasses), etc. Although traffic-calming strategies are primarily promoted as a way to reduce road collisions, injuries and deaths, it is likely that they could, in certain contexts, help reduce vehicle emissions on calmed roads and, sometimes, shift them outside the calmed areas. These changes could affect the quality of the air to which populations are exposed, and thus their health.

3.2.1 Mechanisms of action

According to the studies consulted, traffic-calming strategies can influence air pollutant emissions and ambient air quality by means of three main mechanisms:

a) Reduction of vehicle speeds

The variation of air pollutant emissions according to vehicle speed is well established (Owen, 2005). As illustrated in Figure 15, emissions generally follow fuel consumption, which appears graphically as a U-shaped curve; that is, fuel consumption and emissions per kilometre travelled are greater at low and at high speeds (Sergerie et al., 2005; Environmental Protection Agency [EPA] & U.S. Department of Energy [DOE], 2010; WHO Regional Office for Europe, 2005). Thus, it is not surprising that the "EPA MOBILE Model" (http://www.epa.gov/OMS/mobile.htm) predicts that the slowing down of traffic due to traffic-calming strategies should be accompanied by an increase in emissions (Transportation Research Board, 1995).

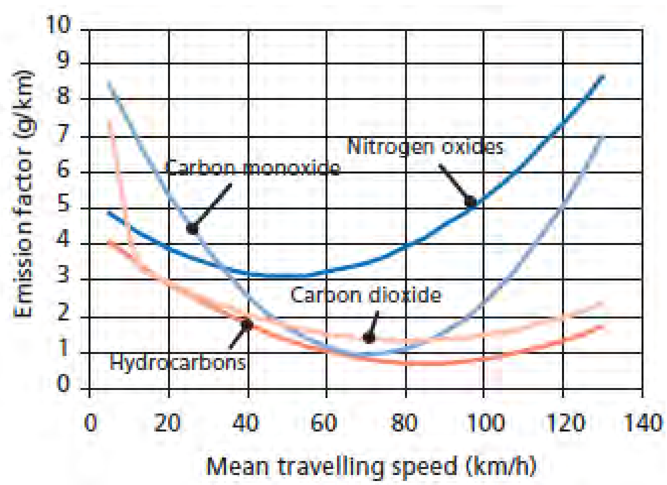

Figure 15 Effect of mean travelling speed on emission levels from passenger cars with catalysts

Note: Values for nitrogen oxides (NO_x) and hydrocarbons (HC) have been multiplied by 10 and those for carbon dioxide (CO_2) have been divided by 100.

Sources: Adapted from Ntziachristos & Samaras, 2000, in WHO Regional Office for Europe, 2005, p. 25. Copyright 2000, reprinted with permission from Elsevier.

b) Reduction of speed variations

Accelerations, decelerations and idling time also influence vehicle pollutant emissions, because a combustion engine consumes more fuel when turning slowly, while a vehicle is idling, or when accelerating, than when it is turning at a constant speed (EPA & DOE, 2010; Bahar, Smahel, & Smiley, 2009). The increased fuel consumption that results from frequent variations in driving speed and the less complete combustion that occurs during accelerations produce an overall increase in emissions (Houwing, 2003; Sergerie et al., 2005). Frequently varying speed while driving thus tends to produce more air pollutant emissions than driving at a constant speed, which explains, moreover, the difference in the emission levels associated with aggressive and calm driving styles (Owen, 2005; EPA & DOE, 2010; Houwing, 2003). The configuration of calming measures (which generally determines the speed at which they can easily be negotiated), their spacing (which determines the potential for acceleration and deceleration between them) and how they manage right of way at intersections (which determines accelerations, decelerations and idling time at intersections) should therefore influence their impact on pollutant emissions. Thus, interventions succeeding in reducing speed variations should contribute to decrease pollutant emissions by vehicle.

c) Reduction of traffic volume

Air pollutant emissions from motor vehicles vary in accordance with the number of trips taken and the distance travelled in motor vehicles. Given the reduced effectiveness of catalytic converters during the first few minutes of driving and the emissions caused by initial acceleration, WHO Regional Office for Europe estimated in 2005 that approximately 90% of air pollutants are emitted during the first 200 seconds that a car is in motion when travelling less than 6 km in a city (WHO Regional Office for Europe, 2005). Since a significant number of motor vehicle trips taken in urban settings cover short distances,[18] a change in the number of such trips (due to an increase in walking or cycling trips, for example) should have a greater effect on total emissions than an increase or decrease in the distances travelled. When calming strategies succeed in reducing the volume of motor vehicle traffic, by increasing walking, for example, this should result in a reduction in emissions and an improvement in air quality, whereas pollutant emissions may simply be displaced if traffic is diverted from one area to another.

Most of the studies consulted that examine the effects of traffic-calming strategies on air pollutant emissions and air quality inferred these effects by referring to the three mechanisms above, without attempting to measure the effects. We have retained for purposes of analysis only those studies that evaluated the effects of one or of a series of calming measures. As in the preceding section, we will first present the data on isolated interventions installed at specific points on the road network or along a single street, followed by the data on area-wide calming schemes.

3.2.2 Effects of isolated traffic-calming measures

3.2.2.1 Objective studies

All the studies consulted that considered the effects of individual interventions on air quality evaluated these effects by examining the air emissions of motor vehicles. Probably because the impact of such interventions is very restricted geographically, only one article (Boulter et al., 2001) attempted to measure their effects on ambient air quality.

A literature review produced by the Transport Research Laboratory (Boulter & Webster, 1997) demonstrates that the results of seven studies conducted prior to 1997 focusing on European interventions at isolated points of the road network or on a single street vary considerably. Table 10 summarizes these results.[19]

[18] An article estimates, for example, that in the Montréal metropolitan region, 11.7% (n=862,000) of trips carried out weekly cover distances of less than 1.6 km and that 55% of these are taken in motor vehicles (Morency, Demers, & Lapierre, 2007). In the United States, according to the authors of one article, 41% of all trips carried out in urban settings cover distances of less than 3.2 km and 28% cover less than 1.6 km, with 89% of Americans using their car for trips of between 1.6 and 3.2 km and 66% for trips covering less than 1.6 km (Pucher & Renne, 2003). In Europe, according to WHO estimates, 30% of car trips cover distances of less than 3 km and 50% cover distances of less than 5 km (WHO Regional Office for Europe, 2011).

[19] To facilitate comparison of the various results, all the tables in the present section have the same columns. This choice explains why some tables have entire columns for which no data are available ("-"). Fuel consumption and CO2 emissions are presented together because their variations are strongly correlated (Boulter & Webster, 1997).

Table 10 Effects of various calming measures on air emissions

Calming measures	**Type of vehicle** (gas-powered cars)	**CO**	**HC**	**CO_2/Fuel**	**NO_x**	**PM**
Speed humps	with and without catalytic converter	+70% to +80%	+70% to +100%	+50% to +60%	-20% to 0%	-
One speed hump	with catalytic converter	+20%	-	+4%	+18%	-
	without catalytic converter	+11%	-	+5%	+22%	-
Ten speed humps	with catalytic converter	+300%	-	+37%	+300%	-
	without catalytic converter	+200%	-	+51%	+300%	-
Various measures, 40-km/h limit	-	-	-	-9%	-	-
Six speed humps	with catalytic converter	+300%	-	+25%	+1000%	-
Five speed humps	-	-	-	+36% to +73%	-	-
Two roundabouts	-	-	-	+33%	-	-

Note: No statistical significance test mentioned.
Source of the data: Boulter & Webster, 1997.

Despite wide variation among the studies, nearly all of them report substantial increases in the various air pollutants measured. According to the authors, a decrease in driving speeds and more frequent speed variations following the interventions explain the increases observed.

To follow up on the variations observed in this literature review, the Transport Research Laboratory undertook to study the specific impact of various calming measures (flat-top and round-top speed humps, raised intersections, speed cushions, chicanes, curb extensions, combination of a road narrowing and a speed cushion, mini-roundabout) on air pollutant emissions and ambient air quality[20] (Boulter et al., 2001). Actual driving speeds were measured without the knowledge of drivers, before and after the installation of calming measures or on street blocks with calming measures and on control street blocks, to establish typical driving cycles for each calming measure. These cycles were then

[20] While the study evaluated the effects of the calming measures taken in isolation, it should be noted that almost half of these were part of area-wide calming schemes. The manner in which the study presents the results does not allow for their separation on the basis of the two approaches to traffic calming.

reproduced under laboratory conditions using three types of cars, to measure the associated emissions. Without offering any real explanation or justification, the authors indicate that seven of the twelve cars used were replaced by other cars of the same type during the experiment. Since this may have compromised the validity of the results, these should be interpreted with caution. Table 11 presents the average variations measured for all the calming measures taken together.

Table 11 Effects of calming measures on air emissions according to type of vehicle

Calming measure	**Type of vehicle** (cars)	**CO**	**HC**	**CO_2/Fuel**	**NO_x**	**PM**
Various measures	Gas with catalytic converter	+59%*	+54%*	+26%*	+8%	-
	Gas without catalytic converter	+34%*	+50%*	+20%*	+1%	-
	Diesel	+39%*	+48%*	+26%*	+28%*	+30%*

* Significant variation at $p < 0.05$.

Source of the data: Boulter et al., 2001.

These results show that, apart from the NO_x emitted by gas-powered cars, the calming measures, on average, led to significant increases in the emission of most pollutants. To determine the impact of these increases on air quality 10 metres from road centres, the authors used a dispersion model. The results take into consideration reduced traffic volume recorded at one site and increases at four other sites following the interventions, but the author does not specify when these measurements were taken. The results also take into account the traffic volume of heavy vehicles, basing calculations on the relationship, established in a previous study, between the speed and the average emissions of such vehicles. Based on the proportion of vehicles with and without catalytic converters circulating in England in 2000, the authors estimated that the interventions had, on average, the following effects on air quality: +0.4% to +6.7% for CO, +2.7% to +10.1% for benzene, +2.7% to +9.5% for 1,3-butadiene, and -0.4% to +4.3% for NO_2. The reported values seem to indicate a slight deterioration in air quality, but in the absence of any statistical significance test, and given the unexplained increases in traffic volumes, these results should be interpreted with caution.

In 2005, the Society of Automotive Engineers International published a report (Daham, Andrews, Li, Partridge, Bell, & Tate, 2005) on the impact of speed humps on air pollutant emissions. However, the method used casts doubt on the validity of the results obtained. To simulate a road without speed humps, the authors drove at a constant speed of 50 km/h on a road with seven speed cushions installed on it, and to simulate the presence of seven 80 mm speed humps (the highest kind), they drove on the same road, slowing down to 16 km/h to go over the speed cushions and accelerating up to 32-50 km/h between them. Using equipment installed on the car to measure emissions in real time, they simulated the impact of speed humps on a car with a very heavy load, thus producing results that are probably not very representative of a car with an average load. Moreover, by slowing down more than necessary to easily go over the simulated speed humps, and then accelerating rapidly between the speed humps, the authors simulated an aggressive driving style, which probably led to an overestimation of average emissions on the calmed road. Indeed, the authors state that their results are "probably a representation of an unsmooth driver who is in a hurry to negotiate a traffic-calmed road driving a heavily laden car" (Daham et al., 2005, p. 14). Table 12 summarizes the results obtained.

Table 12 Effects of speed humps on air emissions

Calming measures	Type of vehicles (gas-powered cars)	CO	HC	CO_2/Fuel	NO_x	PM
Speed humps	With catalytic converter	+117%	+148%	+90%/+35%	+195%	-

Note: No statistical significance test mentioned.
Source of the data: Daham et al., 2005.

According to these results, speed humps engender significant increases in air emissions. However, by changing the driving style (from calm to aggressive) between the control cycle and the experimental cycle, the authors introduced a confounding factor into their study. Moreover, these results are probably not representative of a car with an average load. Therefore, these results should be interpreted with caution.

An article by Ahn & Rakha (2009) presents the results of a study in which speeds and speed variations were measured on three roads and air pollutant emissions were calculated using a computer model. The first road had a speed limit of 40 km/h: driver speeds were measured before and after the installation of five speed cushions. On the second road, whose speed limit was 25 km/h, speeds were measured before and after the installation of two speed bumps.[21] On the third road, whose speed limit was 40 km/h, the impact of the calming measures was determined by having a car driven on the road as illustrated in Figure 16. The pollutants emitted at intersections without calming measures were compared to those of calmed intersections.

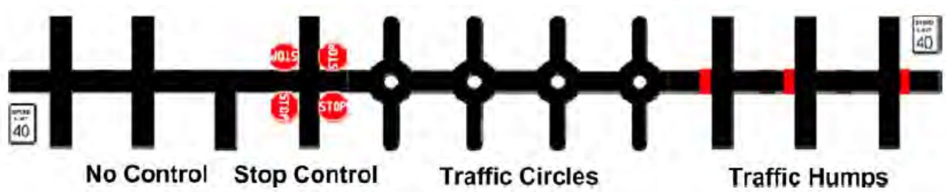

Figure 16 Diagram of a road with calmed intersections

Source: Reprinted from Ahn & Rakha, 2009, p. 414, Copyright 2009, with permission from Elsevier.

[21] It is important to distinguish between "speed bumps" and "speed humps." While the former are narrow (often less than 30 cm across) and are crossed at very low speeds (5-10 km/h), the latter form a broader platform (typically 3 to 4 m across) and are crossed at higher speeds (typically 30 km/h). The former are usually installed in alleys and parking lots, whereas the latter are usually installed on local streets, where slow vehicle speeds are desired.

On the first two roads, the presence of calming measures significantly increased per car emissions of the various pollutants. On the third road, intersections with calming measures gave rise to significantly higher emissions than intersections without calming measures or stop signs. However, on the latter road, the authors did not calculate the emissions of vehicles on cross streets. Yet, the calming measures introduced probably affected speeds and speed variations on these streets by changing how the right of way was managed at the intersections. When calming measures cause traffic to flow more freely on cross streets, by replacing stop signs with a mini-roundabout, for example, this is likely to lead to a decrease in emissions on these streets. Because of this omission, the results for the third road cannot be considered representative of the total impact of the calming measures on air pollutant emissions. For this reason, the results for the third road (stop signs, mini-roundabouts, speed humps) must be interpreted with caution. Table 13 summarizes the results for the three roads studied.

Table 13 Effects of calming measures on air emissions

Calming measures	Road	Type of vehicles (cars)	CO	HC	CO_2/Fuel	NO_x	PM
Speed cushions	1st	Gas	+47%*	+54%*	+48%*	+98%*	-
Speed bumps	2nd	Gas	+9%	+20%*	+29%*/+33%*	+19%*	-
Stop signs	3rd	Gas	+145%*	+125%*	+112%*/+114%*	+264%*	-
Mini-roundabouts	3rd	Gas	+20%*	+31%*	+35%*/+34%*	+56%*	-
Speed humps	3rd	Gas	+44%*	+51%*	+52%*/+53%*	+110%*	-

* Significant variation at $p < 0.05$.
Source of the data: Ahn & Rakha, 2009.

Whether or not they are considered traffic-calming measures by specialists, stop signs are often initially seen as a traffic-calming panacea by residents faced with a traffic problem (Ewing, 1999). Notwithstanding the weaknesses of the article, it is worth noting that this is the intervention that led to the greatest increase in air pollutants, a result that might calm residents' enthusiasm for stop signs and lead one to consider that replacing intersections controlled by stop signs with mini-roundabouts could, depending on the context, help reduce vehicle emissions.

3.2.2.2 Subjective study

An article (Morrison, Thomson, & Petticrew, 2004) evaluates the perception of residents living on a road in Glasgow, Scotland, six months before and six months after the installation of several calming measures (five pairs of speed cushions, parking bays, and two zebra crossings). Of the 750 residents randomly selected to fill out the postal questionnaire, 244 answered before the intervention and 185 answered afterwards. They were asked to evaluate their feelings about problems related to their environment, using a scale of 1 to 7 (1 being the happiest and 7 the unhappiest). Having compared the answers given before and after the intervention, the authors found a significant improvement of 2.88 points in answers to the question regarding traffic fumes.

3.2.2.3 Summary of results for isolated traffic-calming measures

The documentary search led to the identification of two articles (Ahn & Rakha, 2009; Morrison et al., 2004) belonging to the scientific literature, one of which examines residents' perceptions (Morrison et al., 2004), and three studies (Boulter & Webster, 1997; Boulter et al., 2001; Daham et al., 2005) drawn from the grey literature, including a traditional literature review (Boulter & Webster, 1997). These studies evaluate the effects of individual calming measures on air emissions and air quality. They use different methodological approaches and are not all equally rigorous, but they present results which, overall, converge and agree with the recognized mechanisms of action. The key points to recall are the following:

a) Increase in per vehicle emissions

All of the objective studies report that the majority of isolated interventions led to increases of varying size for per vehicle emissions. The two studies (Boulter et al., 2001; Ahn & Rakha, 2009) that mention statistical significance tests report statistically significant increases for most of the pollutants measured. These results are linked to reduced traffic speeds and to an increase in speed variations caused by most of the isolated interventions. Nevertheless, it is still possible that interventions which reduce speed variations on top of traffic speeds can also reduce vehicle emissions (Ahn & Rakha, 2009).

b) Slight deterioration of air quality

The only study (Boulter et al., 2001) that evaluates air quality on calmed roads reports a slight deterioration, on average, of air quality following interventions, but traffic volumes increased on most of the roads studied, and no information is provided about the statistical significance of the results.

c) Perception

Contrary to what the objective studies may lead one to expect, one article (Morrison et al., 2004) reports that residents of a calmed road were significantly less unhappy about vehicle emissions after calming measures were introduced.

d) Promising calming measures

Without providing conclusive evidence, one article (Ahn & Rakha, 2009) indicates that replacing an intersection managed with stop signs by a mini-roundabout could, by reducing vehicle speed variations, reduce per vehicle pollutant emissions.

3.2.3 Effects of area-wide calming schemes

3.2.3.1 Objective studies

Area-wide strategies are often used not only to reduce driving speeds, but also to reduce traffic volumes in the areas where they are implemented. Thus, some studies took into account reductions in volume when evaluating the effects of area-wide strategies on air emissions and air quality.

The traditional literature review carried out by Boulter & Webster (1997) examines the six studies that focus on area-wide strategies separately. The review specifies that the studies examined the effects of speed without taking into account the reduction in traffic volume that may have occurred following the interventions. Table 14 presents the variations in emissions measured following the interventions.

Table 14 Effects of various area-wide strategies on air emissions

Calming measures	**Type of vehicles** (gas-powered cars)	**CO**	**HC**	**CO_2/Fuel**	**NO_x**	**PM**
Area with extensive traffic calming[a]	Without catalytic converter	+7% to +71%	-25% to -10%	+7% to +19%	-60% to -38%	-
30-km/h zone	Without catalytic converter	-20% to +28%	-23% to +2%	-6% to +14%	-31% to -5%	-
Speed hump scheme	-	Slight increase	No change	-	Decrease	-
Area with extensive calming	-	Increase	Increase	-	Decrease	-
21 mini-roundabouts, 30-km/h limit[b]	-	+2%	-	+<1%	+1%	-

[a] This is the expression used by the authors of the literature review, although they do not define it.

[b] Boulter & Webster (1997) classify this study among those evaluating cases where a series of calming measures were installed on one road. However, the evaluation is of an area-wide scheme involving the installation of 21 mini-roundabouts on more than one street in Växjö, Sweden, also evaluated by Hyden & Várhelyi (2000) and Várhelyi (2002); which is why it is presented in this section.

Note: No statistical significance test mentioned.

Source of the data: Boulter & Webster, 1997.

All of these studies report a decrease in NO_x emissions or a negligible effect on them, but note variable results with respect to the other pollutants.

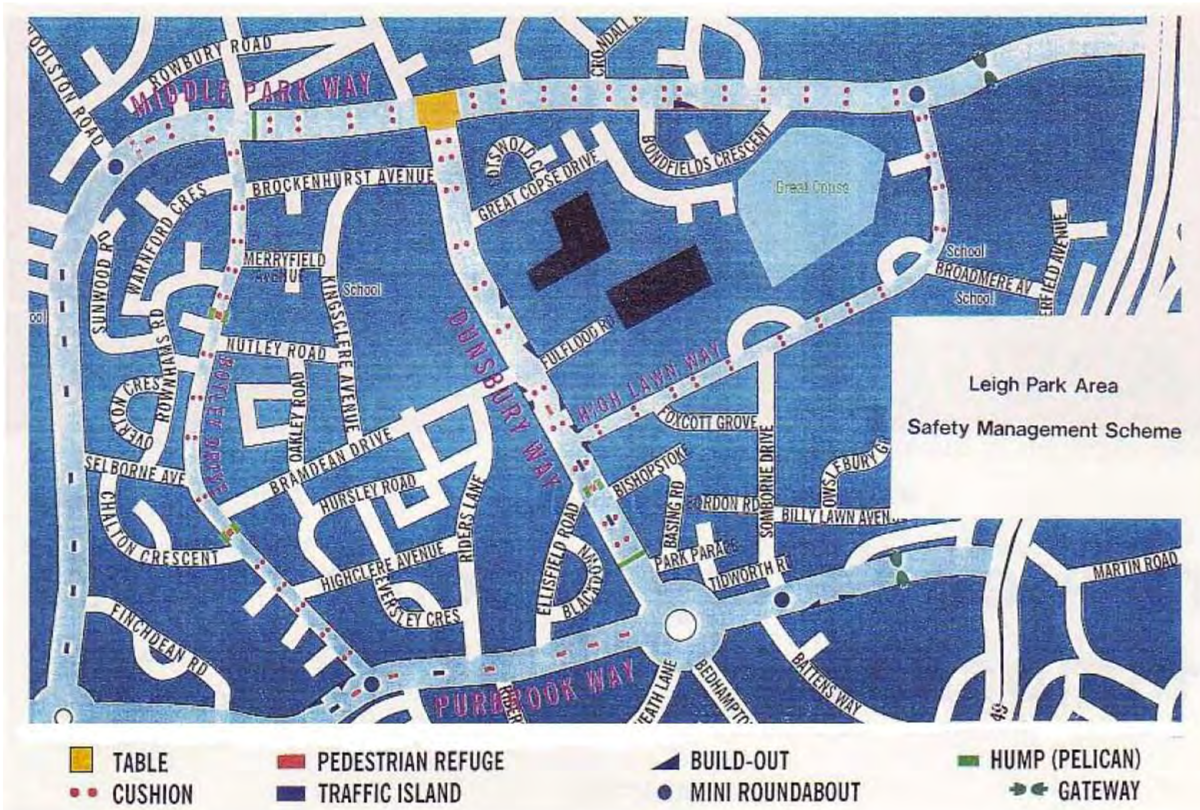

Figure 17 Leigh Park area calming scheme

Source: Department for Transport, 1999, p. 2.

In 1999, the Transport Research Laboratory published a report (Cloke et al., 1999) evaluating the environmental impact of an area-wide traffic-calming scheme involving the installation of several types of calming measures in the Leigh Park area of Havant, England. Figure 17 shows the calming measures installed and their distribution in the area. The speeds and speed variations of 20 subjects who drove through the zone were measured to establish driving cycles. On roads calmed with speed cushions, traffic volume reductions of 15% to 35% and speed reductions of 18-19 km/h were recorded at the locations where the speed cushions were installed. It was estimated that 10% of traffic was diverted outside of the calmed sector, the equivalent of approximately 600 fewer vehicles per day in the area. Variations in vehicle emissions, calculated using a computer model, are presented in Table 15.

Table 15 Effects of the Leigh Park traffic-calming scheme on air emissions

Air emissions	Type of vehicles (gas-powered)	Vehicle emissions				
		CO	HC	CO_2/ Fuel	NO_x	PM
Emissions on roads with speed cushions (without taking into account volume reduction)	Cars	+22%	+24%	+9%	-12%	-
Emissions on roads with speed cushions (taking into account volume reduction)	Cars and heavy vehicles	-8%	-7%	-12%	-22%	-
Emissions on roads calmed with other measures (taking into account volume reduction)	Cars and heavy vehicles	-4%	-2%	-4%	-8%	-
Emissions for the area	Cars and heavy vehicles	-6%	-5%	-8%	-15%	-

Note: No statistical significance test mentioned.
Source of the data: Cloke et al., 1999.

With the exception of NO_x emissions per vehicle, which decreased, the calming of roads resulted in an increase in per vehicle pollutant emissions. Nevertheless, when the reduction in traffic volumes is taken into account, the result is a decrease in emissions on roads calmed and in the entire area, although the study does not indicate whether these results are statistically significant. Based on measurements of NO_2 and benzene (a type of HC) taken using diffusion tubes distributed at 6 sites, including 2 control sites outside the area, before and after the interventions, a non-significant improvement, at $p < 0.05$, in air quality (-5% benzene, -1% NO_2) was observed in the area, as compared to control sites. Thus, the creation of the zones did not significantly affect the air quality within them.

Várhelyi (2000) published an article evaluating the effects of a scheme involving the installation of 21 mini-roundabouts in Växjö, Sweden, on the fuel consumption and emissions of cars. Driving cycles were observed before (n=600) and after (n=800) the installation of the mini-roundabouts. Measurements were made using a car equipped to record the distance it travelled every two seconds, making it possible to determine travelling speed and speed variations. The driver of this car copied the movements of other randomly selected drivers, without their knowledge. The information recorded was used to establish typical driving cycles. The fuel consumption and emissions resulting from these typical driving cycles were calculated using a model that took into account traffic volumes at the various branches of the intersections, which did not vary significantly following the intervention. The calculations simplified reality by assuming that all the vehicles counted were cars (whereas heavy vehicles represented about 7% of traffic), that they were all gas-powered and that 30% of them were equipped with a catalytic converter. Table 16 summarizes the results obtained.

Table 16 Effects on air emissions of a scheme involving installation of 21 mini-roundabouts

Calming measures	Type of vehicles (gas-powered cars)	CO	HC	CO_2/Fuel	NO_x	PM
Mini-roundabout replacing an intersection without signals	30% with catalytic converter	+6%	-	+3%	+4%	-
Main road	30% with catalytic converter	+13%*	-	+8%	+8%	-
Secondary road	30% with catalytic converter	-20%	-	-21%	-15%	-
Mini-roundabout replacing an intersection with traffic lights	30% with catalytic converter	-29%	-	-28%	-21%	-

* Significant variation at $p < 0.05$.
Source of the data: Várhelyi, 2002.

Although only one result was statistically significant, all the results in this article agree with the outcomes expected based on the mechanisms of action: a decrease in emissions following improved flow at secondary road intersections previously without signals (where vehicles systematically yielded passage); a decrease in emissions following a decrease in speed variations at a mini-roundabout replacing an intersection with traffic lights (where all vehicles on each of the branches alternated stopping); and an increase in emissions following the slowing down of traffic at intersections on main roads previously without signals (where vehicles systematically had right of way). Even though the results concerning the mini-roundabout replacing an intersection with traffic lights are not statistically significant (probably because a single roundabout was evaluated), the point estimates suggest that this intervention holds promise as a way to reduce emissions. The article points to the importance of the implementation context of an intervention and of the distribution of traffic volumes on the different branches of an intersection in determining the effects of a calming measure installed at an intersection, but the results regarding the overall effect of the area-wide scheme on per vehicle emissions are inconclusive.

In another article, Owen (2005) evaluated the effects on pollutant emissions and air quality of six 20-mph (32-km/h) zones implemented in North West England. The six zones studied were relatively small (approximately 0.5 km x 0.5 km). Speed in the zones was controlled by physical traffic-calming measures, such as speed humps and traffic lights. Measurements of ambient concentrations of NO_2 and benzene were taken before (5 to 9 months) and after (3 to 12 months) the creation of the zones. These measurements were taken at three sites within each zone and at one control site using diffusion tubes and thermal desorption tubes, which are subject to wide margins of error (±25% for diffusion tubes). On the basis of these measurements, the article concludes that the introduction of calming measures neither improved nor worsened air quality significantly in the six zones. Basing calculations on average driving speeds within five of the six zones, the author found that per vehicle emissions rose (0% to +5% NO_x; +11% to +34% benzene), but when variations in traffic volume were taken into account, emissions were found to have decreased in the majority of zones (+8%, -18%, -9%, -32% and -80% NO_x; +22%, +3%, -15%, -32% and -76% benzene).

However, using average speeds to calculate emissions can lead to the underestimation or overestimation of emissions by failing to consider the effect of speed variations. A dispersion model indicated that local traffic was responsible for a small percentage of ambient concentrations of NO_x and, more specifically, of NO_2 (4% to 14% of NO_x; 0% to 3% of NO_2). This weak contribution to NO_x levels and the use of relatively imprecise measuring equipment probably explains, at least in part, why no significant variation in air quality was measured following the interventions.

3.2.3.2 Subjective studies

Within the context of the report on Leigh Park (Cloke et al., 1999), discussed previously, interviews before (n=151) and after (n=150) implementation of the calming measures were carried out with groups of residents, in particular, to determine their perception of airborne nuisances in the area. The report does not specify how the interviews were carried out or how participants were selected. Moreover, only 113 residents participated in the interviews both before and after the intervention, and the results are not accompanied by statistical significance tests. Due to these limitations, the results should be interpreted with caution. The majority of respondents (68%) had perceived no change with respect to airborne nuisances (dust, dirt, fumes, smoke) when out walking after the interventions. Of those who perceived a difference, the majority reported an increase in nuisances (21%, versus 10% who perceived a reduction). However, the percentage of respondents who reported being “very much” or “quite a lot” bothered by dust or dirt (42% before/46% after) or by smoke (42% before/38% after) in their homes remained basically the same.

The report prepared by Hemsing & Forbes (2000) for the City of Ottawa and the Ottawa-Carleton region presents the perception of the residents of calmed roads and zones according to the type of road on which they live (local, collector or arterial) and the type of calming measure installed (horizontal, vertical or a combination of both). The survey was conducted using questionnaires distributed on a non-random basis to residents of already-calmed roads. Thus, the representativeness of the sample cannot be affirmed, the less so since on some roads only a few surveys were filled out. For these reasons, the results should be interpreted with caution. Table 17 summarizes the views of residents, as reported in the report’s appendices.

Table 17 Effects of calming schemes on air quality as perceived by residents

Calming measures	Types of roads	No change	Don't know	Improvement	Deterioration
Horizontal	Local	27%	31%	-	21%
	Collector	45%	28%	19%	-
	Arterial	41%	28%	18%	-
Vertical	Local	13%	55%	13%	-
	Collector	39%	24%	26%	-
	Arterial	48%	27%	12%	12%
Horizontal and vertical	Local	37%	18%	34%	-
	Collector	-	-	-	-
	Arterial	43%	30%	18%	-

Note: No statistical significance test was mentioned, but the lines with underlined numbers indicate a greater proportion of respondents having perceived an improvement, as opposed to a deterioration, in air quality; whereas those remaining in plain text indicate the absence of or inability to establish such a relationship or its inverse.

Source of the data: Hemsing & Forbes, 2000.

According to these results, the majority of respondents observed no change in air quality or did not know if there had been one. Nevertheless, for most road categories, more respondents perceived an improvement in air quality than perceived a deterioration.

3.2.3.3 Summary of results for area-wide calming schemes

The documentary search led to the identification of two articles (Várhelyi, 2002; Owen, 2005) belonging to the scientific literature and three studies (Boulter & Webster, 1997; Cloke et al., 1999; Hemsing & Forbes, 2000) drawn from the grey literature, including one traditional literature review (Boulter & Webster, 1997) and two studies that examined residents' perceptions (Cloke et al., 1999; Hemsing & Forbes, 2000). These studies evaluate the effects of area-wide calming schemes on air emissions and air quality. They use different methodological approaches and are not all equally rigorous, but they present results which, overall, agree with the recognized mechanisms of action. The key points to recall are the following:

a) Variable effects on per vehicle emissions

The traditional literature review (Boulter et al., 1997) reports both increases and decreases as well as a lack of change with respect to per vehicle emissions of the various pollutants following the implementation of area-wide schemes, with the exception of NO_x emissions for which it reports no increases. One article (Owen, 2005) reports per vehicle increases in emissions of all pollutants following implementation of the schemes and one study (Cloke et al., 1999) concludes likewise, except that it reports a decrease in per vehicle emissions of NO_x. The only article (Várhelyi, 2002) that mentions statistical significance tests points to the importance of the implementation context, and reports weak, non-significant increases in per vehicle emissions for a mini-roundabout replacing an intersection without signals, but much greater non-significant decreases for the replacement of an intersection controlled by traffic lights. The differences between the results reported by the various studies are likely due, in part, to the variable effects of area-wide schemes on driving speeds, speed variations and time spent idling.

b) Relevance of traffic volumes for total emissions

The two studies (Cloke et al., 1999; Owen, 2005) that take into account increases and decreases in traffic volume in the calmed areas report reductions for emissions of all pollutants in the majority of areas where traffic volumes decreased, although no statistical significance tests accompany these results. One article (Várhelyi, 2002) examining a scheme involving mini-roundabouts points to the fact that interventions can have different effects on vehicles driving on the various branches of an intersection. Thus, the effect of such interventions on total emissions would depend on the amount of traffic on the various branches.

c) Air quality

Despite the variations in per vehicle emissions and in overall emissions in an area, neither of the two studies (Cloke et al., 1999; Owen, 2005) having measured the effect of calming schemes on ambient air quality report significant changes for areas, once the variations at control sites were taken into account. One article (Owen, 2005) suggests that the weak contribution of road traffic in calmed areas to ambient concentrations of atmospheric pollutants may, in certain cases, explain why an increase or a decrease in emissions caused by an area-wide scheme does not necessarily lead to significant variation in measurements of ambient air quality. However, the imprecision of the measuring devices used could also explain the absence of significant results.

d) Perception

The two studies (Cloke et al., 1999; Hemsing & Forbes, 2000) that examined residents' perceptions report that a majority did not observe any change in air quality following the interventions.

e) Promising area-wide strategies

None of the studies consulted compare the effects of area-wide strategies. Nevertheless, two studies (Cloke et al., 1999; Owen, 2005) report reductions in emissions following the implementation of schemes that reduced traffic volumes, while one article (Várhelyi, 2002) implies that mini-roundabouts replacing traffic lights can, when they result in fewer speed variations and less time spent idling, help reduce per vehicle emissions.

3.2.4 Conclusion of the section on air quality

3.2.4.1 Section summary

Traffic-calming interventions are not usually promoted as a way of improving air quality, but rather as a way of reducing the number of collisions, injuries and deaths. While, generally speaking, they can be said to improve road safety, the literature is less abundant and less conclusive concerning their effects on air pollutant emissions and ambient air quality. Nevertheless, most studies indicate that the implementation of calming measures generally leads to an increase in per vehicle emissions of the main air pollutants, even though certain calming measures, such as mini-roundabouts, are more likely to reduce them in certain contexts. Increases in per vehicle emissions can be explained by a decrease in speeds or an increase in speed variations and time spent idling, whereas decreases in emissions can be explained by the inverse phenomena. The studies also indicate that when a traffic-calming intervention leads to a reduction in traffic volumes, this can compensate for an increase in per vehicle emissions or even lead to an overall reduction in emissions at the intervention site. According to the studies consulted, the residents of calmed areas do not always perceive these changes. Despite increases and decreases in air pollutant emissions, the studies do not report any significant variation in air quality in the vicinity of the interventions, but this result may be due to the imprecision of measuring devices. The explanatory mechanisms lead one to expect that the strategies most effective at reducing emissions at intervention sites are those that reduce speed variations, idling times and traffic volumes at those sites. According to the logic of these mechanisms, area-wide strategies, which often explicitly aim to reduce traffic volumes in an area, seem to have an advantage over targeted interventions, which do not generally seek to alter traffic volumes. However, area-wide strategies that divert motorized traffic instead of reducing it (e.g., by promoting active transportation) risk displacing pollutants rather than reducing pollutant emissions, and, in certain contexts, this may increase health inequalities.

3.2.4.2 Research gaps

Effects of local traffic on air quality

Traffic-calming interventions, depending on the measures implemented and the context, can lead to an increase or a decrease in emissions at intervention sites. While some studies have sought to quantify these variations, only one article (Owen, 2005) has calculated the contribution of these local emissions to ambient concentrations of atmospheric pollutants. The article in question indicates that, for the area-wide schemes it evaluated, local emissions contributed little to ambient concentrations of pollutants, which may explain why the studies consulted (Boulter et al*.*, 2001; Cloke et al*.*, 1999; Owen, 2005) report no significant increase or decrease in ambient air quality following an increase or decrease in these emissions. To improve understanding of the health effects that may be linked to an increase or a decrease in local emissions, it would be relevant to conduct studies to determine, in various contexts, the portion of atmospheric pollutants that can generally be attributed to emissions on the roads where most calming measures are installed, that is, on local streets lined with homes.

Accuracy of measuring devices

In a similar vein, the three studies (Boulter et al*.*, 2001; Cloke et al*.*, 1999; Owen, 2005) having evaluated the effects of traffic calming on ambient air quality used rather imprecise measuring devices (e.g., diffusion tubes). It would be relevant to conduct research using more precise devices (e.g., continuous analyzers), to determine whether or not interventions have a significant effect on ambient air quality.

Inequalities

The area-wide approach to traffic calming often aims to redirect a portion of traffic on local streets toward the arterial network. Given that persons with low socioeconomic status tend to be overrepresented among residents of these roads (Smargiassi et al*.*, 2006), it would be relevant to conduct research into the potential effects of area-wide strategies on inequalities in exposure to air pollutants from road traffic.

Greening

Also, traffic calming often results in the recovery of space formerly devoted to automobile traffic. This reorganization of public space often presents opportunities for greening which can, moreover, affect ambient air quality (Beckett, Freer-Smith, & Taylor, 1999; Yang, McBride, Zhou, & Sun, 2005) and the amount of greenhouse gases released into the atmosphere (Nowak & Crane, 2002). It would be relevant to conduct research into this potential opportunity for greening.

Figure 18 A "green" mini-roundabout

Source: SkyscraperPage Forum, 2011. Photographer: SFUVancouver.

3.3 ENVIRONMENTAL NOISE

Environmental noise generally refers to sounds considered undesirable or harmful emitted by any source, except noise at the industrial workplace (WHO, 1999). The principal effect of environmental noise is the disturbance of sleep, which can lead to fatigue and feelings of depression, and can lower performance levels. On a daily basis, it can interfere with communication processes, concentration, memory and complex problem solving (WHO, 1999). Prolonged exposure to environmental noise can, notably, increase consumption of tranquilizers and sleeping pills, psychiatric symptoms, psychiatric hospital admissions, stress-related hormones, the risk of hypertension, obesity, and ischaemic heart disease (WHO, 1999; WHO Regional Office for Europe, 2009). Since motorized traffic is one of the main sources of environmental noise (WHO Regional Office for Europe, 2009), it thus contributes to the deterioration of quality of life and to increases in the incidence and prevalence of certain chronic diseases and mental illnesses. Canada does not seem to have been unaffected by this problem, for it has been estimated that 1.8 million Canadians were "very" or "extremely annoyed" by traffic noise in 2003 (Michaud, Keith, & McMurchy, 2005). This said, various actions can be taken to help reduce environmental noise caused by traffic or the population's exposure to it. In particular, noise can be curtailed at its source (e.g., quiet technologies, reduction of traffic volumes), mitigated (e.g., acoustic barriers, insulation of homes) or distanced from populations (e.g., diversion of traffic). Although traffic-calming strategies are primarily promoted as a way to reduce road collisions, injuries and deaths, it is likely that they could also help reduce traffic noise and exposure to this noise, in particular, by reducing traffic speeds and volumes, and by distancing a portion of traffic from sensitive locations (e.g., homes, schools, etc.).

3.3.1 Mechanisms of action

According to the studies consulted, traffic-calming strategies can influence motorized traffic noise by acting on five mechanisms:

a) Reduction of vehicle speeds

Vehicle noise increases with speed. As Figure 19 shows, this association is stronger for cars than for heavy vehicles (commercial vehicles and buses), whose noise is mainly generated by the engine and the exhaust system, which does not vary much with speed, unlike the noise caused by the friction of tires on pavement (Abbott, Tyler, & Layfield, 1995). Thus, by reducing driving speeds, calming measures should mainly help reduce the amount of noise generated by cars.

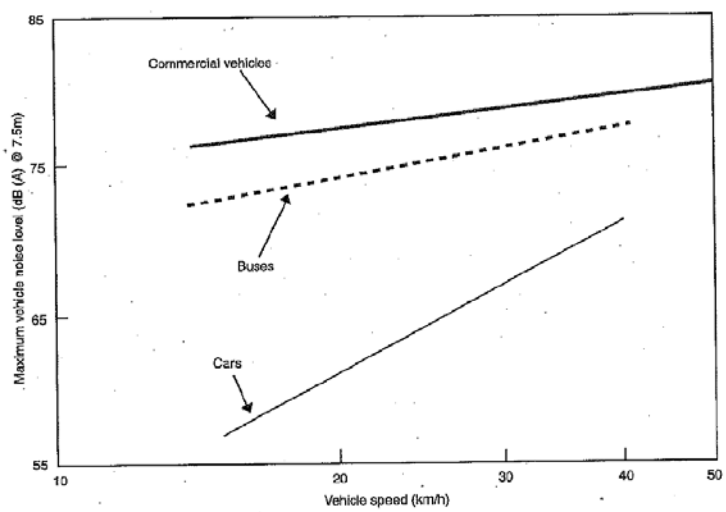

Figure 19 Increase in maximum vehicle noise level according to speed for three types of vehicles

Source: Abbott et al., 1995, p. 9.

b) Reduction of speed variations

Increasing the magnitude, the frequency and the speed of accelerations and decelerations tends to increase the noise generated by accelerating motors and by brakes, for example. Traffic-calming strategies can lead to speed variations when, for example, a driver is navigating a speed hump, but they can also encourage driving at slow and constant speeds when calming measures are close enough to discourage accelerating and decelerating between them. Thus, the impact of calming strategies on vehicle noise levels tied to speed variations is likely to depend on the configuration of calming schemes. Those who succeed in reducing speed variations are likely to contribute to decreasing traffic noise.

c) Reduction of traffic volume

The effect of variations in traffic volume on noise is complex. The presence of fewer vehicles on a road or in an area can lead, depending on the context, to higher driving speeds. These can lead to an increase in the maximum noise level of vehicles. Inversely, heavier traffic can slow vehicles down and thus decrease their maximum noise level. However, heavier traffic can also lead to congestion and thus increase noise due to braking mechanisms, frequent stops, etc. Considering another noise measurement, an increase in the number of vehicles travelling on a road or in an area can also increase the average noise level (see Box 3 for a discussion of these different measurements). The impact of calming strategies on environmental noise attributable to a change in traffic volume therefore depends on the indicators used to measure noise and on several other factors, such as the conditions determining driving speeds and road capacities before and after calming.

d) Introduction of textured materials

Textured materials, such as paving stones, can increase noise from vehicles travelling over them by causing their bodywork to vibrate, for example. The use of calming measures incorporating such materials is thus likely to contribute to an increase in traffic noise.

Figure 20 Textured crosswalk

Source: www.flickr.com. Photographer: Richard Drdul.

e) Introduction of vertical deflections

A large vertical deflection (e.g., speed hump) can increase suspension noises or noise from objects carried in a trailer, for example. Strategies that incorporate calming measures causing such deflections are thus likely to increase noise from vehicles affected by vibrations. The impact of these calming measures therefore depends on their design and on the type of vehicles travelling on the roads where they are used.

Most of the studies consulted that examine the effects of traffic-calming strategies on noise generated by vehicles inferred these effects by referring to the five mechanisms above without attempting to measure the effects. We have retained for purposes of analysis only those studies that evaluated the effects of one or of a series of calming measures. As in the preceding sections, we will first present the data on isolated interventions installed at specific points on the road network, or on a single street or a test track, followed by the data on area-wide calming schemes.

BOX 3 MEASUREMENTS OF ENVIRONMENTAL NOISE AND A FEW POINTS OF REFERENCE

There are several indicators that are useful for determining the effect of an intervention on environmental noise. All of the studies presented in this document used indicators based on the measurement of noise in A-weighted decibels or dB(A), which is a unit of measurement weighted according to a filter, A, to take into account the way the human ear responds to sound frequencies.

Four indicators were used in the studies consulted:

- **L_{Amax}**: The maximum A-weighted sound pressure level. This indicator should be used to measure a limited number of discrete sounds, such as the passage of a few cars at night on a local street with little traffic (WHO, 1999; WHO Regional Office for Europe, 2009).
- **L_{Aeq} T, L_{Anight}, L_{Aday}**: The A-weighted equivalent average sound pressure level for a time period, T, or over an entire night or day. This indicator should be used to measure relatively continuous noise, such as road traffic on a major artery (WHO, 1999; WHO Regional Office for Europe, 2009).
- **L_{A10}**: The A-weighted noise level which is exceeded 10% of the time for a given time period. This indicator, less commonly used today, was widely used to measure the relatively continuous noise of road traffic, but it is generally very strongly associated with the noisiest isolated events, as measured by L_{Amax} (WHO Regional Office for Europe, 2009).
- **L_{A90}**: The A-weighted noise level which is exceeded 90% of the time for a given time period. This indicator, less commonly used today, was used to measure background noise, which excludes the noisiest isolated events, (WHO Regional Office for Europe, 2009).

To provide a few points of reference, the human ear begins to perceive increases or decreases in noise levels beginning with a variation of 3 dB(A) (Direction de la santé publique, 2006). During daytime and evening, an outside noise level of 50 dB L_{Aeq},16h, in residential areas, is associated with moderate annoyance, whereas a level of 55 dB L_{Aeq},16h is associated with high annoyance (WHO, 1999). A level of 55 dB L_{Aeq},16h also causes annoyance in school courtyards (WHO, 1999). At night, at a level of more than 30 dB L_{Anight} (the equivalent average level, L_{Aeq}, taken at night–ideally–for a period of one year), measured near the facades of homes, the effects on sleep (e.g., movements, awakenings) begin to be observed (WHO Regional Office for Europe, 2009). Between 40 and 55 dB L_{Anight}, health effects (e.g., environmental insomnia, hypertension) are observed (WHO Regional Office for Europe, 2009). Above 55 dB L_{Anight}, the sleep of a sizable proportion of the population is disturbed, and cardiovascular effects become the main health concern (WHO Regional Office for Europe, 2009). As regards noise from discrete events, starting at 53 dB L_{Amax} outside (based on a 21 dB(A) difference between inside and outside), biological effects can be observed (e.g., movements, duration of sleep stages), whereas starting at 63 dB L_{Amax}, sleep quality is reduced (e.g., awakenings).

On the basis of these results, the World Health Organization recommends that European countries aim for a threshold of 40 dB L_{Anight} outside of homes and set an interim threshold of 55 dB L_{Anight} (WHO Regional Office for Europe, 2009).

3.3.2 Effects of isolated traffic-calming measures

3.3.2.1 Objective studies

In 1995, the Transport Research Laboratory published a report (Abbott et al., 1995) evaluating the effects of various configurations of calming measures relying on vertical deflection (wide and narrow speed cushions, round-top and flat-top speed humps) on noise from one car, from three buses and from six heavy vehicles. The calming measures were installed on a test track in London, U.K., and the maximum noise level before and after their installation was measured using a microphone located 7.5 m from the road centre and at 1.2 m from the ground. The vehicles were driven on the test track before and after the introduction of the calming measures at constant speeds typical of the average speed observed on roads where the various calming measures had been installed. It is important to note that the fleet of heavy vehicles selected was noisier than the average fleet used in the country (metal suspension, panels subject to vibrations, etc.) and that the use of constant speeds potentially led to an overestimation of noise from suspension systems and loose metal and an underestimation of acceleration and deceleration noises. This stated, Table 18 summarizes the results obtained.

Table 18 Effects of calming measures on the maximum noise level of vehicles moving at constant speeds

Calming measures	Car	Bus	Heavy vehicles
Track without calming measure (before)			
km/h	*45*	*38*	*38*
dB L_{Amax}	71.0	73.7	79.7
Narrow speed cushions (after)			
km/h	*30 (-15)*	*34 (-4)*	*34 (-4)*
dB L_{Amax}	64.4 (-6.6)	74.7 (+1.0)	81.8 (+2.1)
Wide speed cushions (after)			
km/h	*22 (-23)*	*24 (-14)*	*24 (-14)*
dB L_{Amax}	62.3 (-8.7)	73.2 (-0.5)	87.6 (+7.9)
Round-top speed humps (after)			
km/h	*22 (-23)*	*18 (-20)*	*18 (-20)*
dB L_{Amax}	60.9 (-10.1)	69.8 (-3.9)	77.6 (-2.1)
Flat-top speed humps (after)			
km/h	*22 (-23)*	*18 (-20)*	*18 (-20)*
dB L_{Amax}	60.7 (-10.3)	70.0 (-3.7)	85.9 (+6.2)

Note: No statistical significance test mentioned.
Source of the data: Abbott et al., 1995.

At a constant speed, the effect of introducing vertical deflections was, thus, to reduce the maximum noise from the car, to slightly increase or reduce that of the buses and to increase that of the heavy vehicles, with the exception of the round-top speed humps, which reduced the maximum noise levels of these vehicles. It is interesting to note that the presence of round-top speed humps led to reduced maximum noise levels for all three types of vehicles. On the basis of these results, a model with which to estimate the effects of calming measures on ambient averaged noise levels (in dB L_{Aeq}) based on traffic composition was constructed. The results of seven traffic flow scenarios are illustrated in Figure 21.

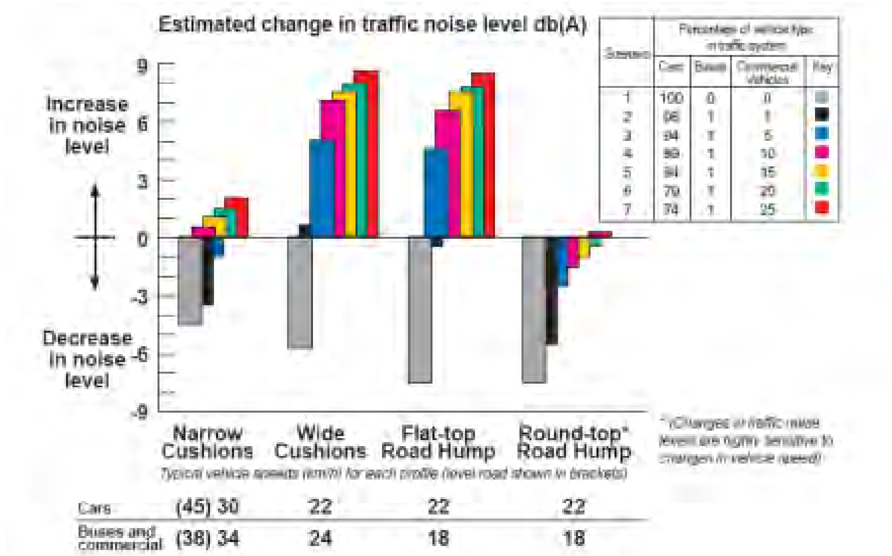

Figure 21 Estimated variations in noise levels after the installation of traffic-calming measures according to traffic composition

Sources: Abbott et al., 1995, p. 20 in Department for Transport, 2007, p. 61.

These results demonstrate that when traffic is composed entirely of cars, the installation of calming measures with vertical deflections should result in a reduction of ambient noise levels. However, the installed measures should generally increase ambient averaged noise levels where heavy vehicles are present. Narrow speed cushions and round-top humps would be preferable where heavy vehicles are present, because they would lead to decreased noise levels even in the presence of 94% cars, 1% buses and 5% heavy vehicles for narrow speed cushions, and of 79% cars, 20% heavy vehicles and 1% buses for round-top humps.

An article by Campolieti & Bertoni (2009) examines the effects on environmental noise levels of replacing an intersection controlled by traffic lights with a roundabout in Modena, Italy. Noise levels were measured before and after the installation using three microphones: two located on the roundabout and one located a few dozen meters away on a branch of the intersection. Although the article specifies that the analyses take into account changes in traffic volume and composition, it should be noted that the methodology used is not explicitly described and that no statistical significance test is mentioned. This said, the article reports averaged noise level reductions of 1 dB L_{Aday} and 2.5 dB L_{Anight}.

3.3.2.2 Subjective study

An article by Morrison et al. (2004) evaluates the perception of residents living on a road in Glasgow, Scotland, six months before and six months after the installation of several calming measures (five pairs of speed cushions, parking bays, and two zebra crossings). Of the 750 residents randomly selected to fill out the postal questionnaire, 244 answered before the intervention and 185 answered afterwards. Respondents were asked to evaluate their feelings about problems related to their environment, using a scale of 1 to 7 (1 being the happiest and 7 the unhappiest). Having compared the answers given before and after the intervention, the authors found a significant improvement of 2.83 points in answers to the question regarding traffic noise.

3.3.2.3 Summary of results for isolated traffic-calming measures

The documentary search led to the identification of two articles (Campolieti & Bertoni, 2009; Morrison et al., 2004) belonging to the scientific literature, one of which examines residents' perceptions (Morrison et al., 2004), and one study drawn from the grey literature (Abbott et al., 1995). These studies evaluate the effects of individual calming measures on noise produced by vehicles. While overall their results converge, by themselves, these three articles have rather limited significance. The key points to recall are the following:

a) Variable effects of vertical deflections on the maximum noise level of vehicles

One study (Abbott et al., 1995) reports that the installation of calming measures with vertical deflections reduces the maximum noise level of cars travelling over the deflections at a constant speed, but that, with the exception of round-top speed humps, these measures tend rather to increase the maximum noise levels of buses and heavy vehicles. These results are attributable to reductions in noise levels caused by decreased speeds and to increased noise from suspension systems and rattling metal when vehicles travel over vertical deflections, but the results do not take into account the speed variations normally observed when this type of calming measure is driven over. Nor are they accompanied by statistical significance tests.

b) Perception

One article (Morrison et al., 2004) reports that the residents of a calmed road were significantly less unhappy about road traffic noise after the road was calmed.

c) Promising calming measures

Without providing conclusive evidence, one article (Campolieti & Bertoni, 2009) indicates that replacing an intersection controlled by traffic lights with a roundabout could, by reducing vehicle speeds and speed variations, reduce ambient averaged noise levels at the intersection. Another study (Abbott et al., 1995) indicates that calming measures with vertical deflections can be effective at reducing noise levels on roads where there are few or no heavy vehicles.

3.3.3 Effects of area-wide calming schemes

3.3.3.1 Objective studies

In 1999, the Transport Research Laboratory published a report (Cloke et al., 1999) evaluating the environmental impact of an area-wide traffic-calming scheme involving the installation of several types of calming measures in the Leigh Park area of Havant, England. Measurements of average driving speeds were carried out before and after the installations, in addition to measurements of maximum noise levels (L_{Amax}) by type of vehicle (light, heavy) and measurements of noise levels that are exceeded 10% (L_{A10}) and 90% (L_{A90}) of the time during the day and at night. Video cameras made it possible to associate maximum noise levels with the various types of vehicles. The authors specify that the increase they measured in the nighttime background noise level ($L_{A90,\ 6h}$) was probably due to the fact that the night on which they took the measurements after the intervention was particularly windy. Table 19 summarizes the results obtained.

Table 19 Effects of calming measures on vehicle speeds and environmental noise

Calming measures	Light vehicles		Heavy vehicles		All vehicles			
	Average speeds (km/h)	L_{Amax}	Average speeds (km/h)	L_{Amax}	$L_{A10,\ 18h}$ (6:00-0:00) day	$L_{A90,\ 18h}$ (6:00-0:00) day	$L_{A10,\ 6h}$ (0:00-6:00) night	$L_{A90,\ 6h}$ (0:00-6:00) night
Mini-roundabout (and speed cushions on one arm of the junction)	-19.3 to -9.3	-3.4 to -1.2	-13.8 to -7.1	+4.5 to +6.2	-4.7	+1.3	-1.1	+7.8
Speed cushions	-21.2 to -19.3	-6.5 to -5.2	-	-	-6.8 to -4.8	-2.7 to -1.0	-2.3 to -0.1	+8 to +9.4
Pedestrian refuge	-7.4	-0.7	-	-	-1.9	+3.4	+2.6	+14.1
Raised intersection	-	-	-	-	-3.6	-2.5	-3.6	+9.6

Note: No statistical significance test mentioned.
Source of the data: Cloke et al., 1999.

These results show that, in general, the strategy led to speed reductions for all vehicles, but that above all, it reduced the maximum noise level of cars and increased that of heavy vehicles. The authors of the report do not explain the increase in the maximum noise level of heavy vehicles at the mini-roundabout, but, according to the logic of the mechanisms of action identified at the beginning of the section, it is likely that the mini-roundabout made it more difficult for heavy vehicles to manoeuvre, thus increasing their speed variations, or that the presence of speed cushions (vertical deflections) resulted in noise from suspension systems or bodyworks. With one exception, the intervention decreased the L_{A10} (the noise levels exceeded 10% of the time), both during the day and at night. The authors believe that the 33 to 35% decrease in traffic volume on the calmed roads brought about by the speed cushions was responsible for a 2 dB $L_{A10,\ 18h}$ daytime reduction, whereas the 10% decrease in traffic at the pedestrian refuge was responsible for a 0.5 dB $L_{A,\ 18h}$ daytime reduction. As regards the measurements of background noise, that is, the noise level exceeded 90% of the time, the daytime results are variable and the validity of the nighttime results is doubtful.

The article by Hyden & Várhelyi (2000) measures the averaged ambient noise levels at three intersections before and after roundabouts were installed, within the context of a scheme involving the installation of 21 mini-roundabouts in Växjö, Sweden. The scheme replaced one intersection controlled by traffic lights and 20 intersections without signals with mini-roundabouts. Although the article specifies that these intersections had daily traffic volumes as high as 23,500 vehicles, it does not indicate, for the intersections studied, the volumes before and after the interventions or the type of intersections replaced. The article concludes that the three mini-roundabouts, by reducing average speeds and speed variations at and between the intersections, were responsible for a reduction in noise levels at the three intersections of 1.6 dB, 3.9 dB and 4.2 dB L_{Aeq}. There is no mention of statistical significance tests for these results.

3.3.3.2 Subjective studies

The report prepared by Hemsing & Forbes (2000) for the City of Ottawa and the Ottawa-Carleton region presents the perception of residents of calmed roads and zones according to the type of road on which they live (local, collector or artery) and the type of calming measure installed (horizontal, vertical or a combination of both). The survey was conducted using questionnaires distributed on a non-random basis to residents of already calmed roads. Thus, the representativeness of the sample cannot be affirmed, the less so since on some roads only a few surveys were filled out. For these reasons, the results should be interpreted with caution. Table 20 summarizes the views of residents, as reported in the report's appendices.

Table 20 Effects of calming schemes on environmental noise as perceived by residents

Calming measures	Types of roads	No change	Don't know	Increase	Decrease
Horizontal	Local	<u>39%</u>	-	<u>16%</u>	<u>31%</u>
	Collector	**51%**	**14%**	**19%**	-
	Arterial	**41%**	-	**21%**	**19%**
Vertical	Local	-	-	**36%**	**28%**
	Collector	**47%**	**12%**	**37%**	-
	Arterial	<u>30%</u>	-	<u>22%</u>	<u>39%</u>
Horizontal and vertical	Local	**42%**	**18%**	**32%**	**12%**
	Collector	-	-	-	-
	Arterial	48%	15%	18%	-

Note: No statistical significance test was mentioned, but the lines with underlined numbers indicate a greater proportion of respondents having perceived an increase in noise levels, as opposed to a decrease in noise levels; whereas the lines with bold numbers indicate the inverse relationship and those remaining in plain text indicate the inability to establish such a relationship.

Source of the data: Hemsing & Forbes, 2000.

According to these results, the majority of respondents seemed not to have noticed any change in ambient noise levels or did not know if there had been one. Nevertheless, for most road categories, more respondents perceived an increase in noise levels than perceived a decrease.

Within the context of the report on Leigh Park (Cloke et al., 1999), interviews before (n=151) and after (n=150) implementation of the calming measures were carried out with groups of residents, in particular, to determine their perception of noise nuisances in the area. The report does not specify how the interviews were carried out or how participants were selected. Moreover, only 113 residents participated in the interviews both before and after installation of the calming measures. Due to these limitations, the results should be interpreted with caution. After the intervention, the majority of respondents observed no change either inside their homes (63%), or when walking outside (58%). Moreover, the percentage of respondents who reported being “very much” or “quite a lot” bothered by noise in their home (38% before/32% after) or when walking outside (33% before/36% after) remained basically the same. Despite these results, significantly fewer respondents indicated that traffic noise prevented them from opening their windows (53% before/28% after). Significantly fewer people mentioned being bothered by noise (38% before/23% after) and by screeching of brakes and tires (48% before/28% after) during the day. Although, prior to implementation of the area-wide scheme, people residing where calming measures were installed had expressed a fear of being more disturbed by noise from vehicles than residents living between two calming measures, the report did not find that the distance of respondents’ homes from the various calming measures significantly affected their answers concerning noise nuisances.

3.3.3.3 Summary of results for area-wide calming schemes

The documentary search led to the identification of one article (Hyden & Várhelyi, 2000) belonging to the scientific literature, and two reports (Cloke et al., 1999; Hemsing & Forbes, 2000) drawn from the grey literature. These studies evaluate the effects of area-wide calming schemes on vehicle noise and residents’ perceptions. While overall their results converge, by themselves, these three studies have rather limited significance. The key points to recall are the following:

a) Reduction of maximum noise level of cars

One study (Cloke et al., 1999) reports reductions in the maximum noise level of cars at all locations where calming measures were installed (mini-roundabout, speed cushions, pedestrian refuge), but no statistical significance tests accompany these results.

b) Increase in maximum noise level of heavy vehicles

The same study (Cloke et al., 1999) reports an increase in the maximum noise level of heavy vehicles at a mini-roundabout equipped with speed cushions; however, no statistical significance tests accompany this result.

c) Reduction of ambient noise levels

Taking into account all noise sources, the same study (Cloke et al., 1999) reports decreases in the noise levels exceeded 10% of the time (L_{A10}) at nearly all locations where measurements were taken, both during the day and at night, but the levels exceeded 90% of the time (L_{A90}) were more variable. One article (Hyden & Várhelyi, 2000) also reports reductions in the noise levels at three intersections replaced with mini-roundabouts. These results are not accompanied by statistical significance tests.

d) Perception

Two studies (Cloke et al., 1999; Hemsing & Forbes, 2000) report that the majority of residents indicated they had not noticed any difference when asked if noise levels had changed after their area was calmed. Nevertheless, one of these studies, having compared the answers before and after, found that significantly fewer respondents said they were disturbed by noise after the interventions (Cloke et al., 1999).

e) Promising area-wide strategies

Without providing conclusive evidence, two studies (Cloke et al., 1999; Hyden & Várhelyi, 2000) support the expectation that a scheme involving the installation of mini-roundabouts that encourage low, constant speeds, in an area where few heavy vehicles circulate, should reduce the intensity of noise events and ambient averaged noise levels in that area. One study (Cloke et al., 1999) also indicates that a scheme incorporating speed cushions, among other measures, to reduce driving speeds and traffic volumes should produce a reduction in the amount of noise generated by cars.

3.3.4 Conclusion of the section on noise pollution

3.3.4.1 Section summary

Traffic-calming interventions are not usually promoted as a way of reducing environmental noise, but rather as a way of reducing the number of collisions, injuries and deaths. While, generally speaking, they can be said to improve road safety, the literature is less abundant and less conclusive concerning their effects on vehicle noise. Nevertheless, most of the evaluative studies indicate that the implementation of calming measures generally leads to a reduction in the maximum noise level of cars and an increase in that of heavy vehicles, with the reported effects on ambient noise levels being more variable. According to the studies consulted, residents of calmed areas may or may not perceive these changes. According to the logic of the mechanisms of action identified at the beginning of the section, the increase in noise from heavy vehicles can be explained, in part, by the presence of vertical deflections, and also by an increase in speed variations. As regards the reduction in the amount of noise generated by cars, this can be explained, in part, by reductions in speed, in speed variations and in traffic volumes. According to the logic of the mechanisms identified, the strategies most effective at reducing traffic noise should be those that reduce speed variations and driving speeds, while reducing traffic volumes and avoiding the use of vertical deflections on routes frequented by heavy vehicles. Based on this same logic, area-wide strategies would seem to have a theoretical advantage over targeted interventions. Indeed, area-wide strategies often explicitly aim to reduce traffic volumes in an area and can be designed to encourage constant speeds, whereas targeted interventions do not generally seek to alter traffic volumes and are less apt to encourage constant speeds throughout an area. However, area-wide strategies that divert motorized traffic instead of reducing it (e.g., by promoting active transportation) can contribute to an increase in noise levels elsewhere on the road network, which, in certain contexts, may increase health inequalities.

3.3.4.2 Research gaps

Speed variations

The frequency and intensity with which vehicles navigating a calming measure accelerate and decelerate should influence the effects of calming strategies on ambient noise levels. Thus, it would be relevant to conduct research into the effects of the various strategies and the calming measures they include on speed variations and the noise generated by cars and by heavy vehicles.

Materials

Many calming measures can be constructed using more than one material: pedestrian crossings can, for example, be built from asphalt or from paving stones, just as speed humps can be fixed and made of asphalt or movable and made of polyurethane. It would be relevant to conduct research into the effects of these materials on vehicle noise.

Inequalities

The area-wide approach to traffic calming often aims to redirect a portion of traffic on local streets toward the arterial network. Given that persons with low socioeconomic status tend to be overrepresented among residents of these roads (Smargiassi et al., 2006), it would be relevant to conduct research into the potential effects of area-wide strategies on inequalities in exposure to environmental noise.

Greening

Since the presence of vegetation can help mitigate sound propagation (Fang & Ling, 2003), traffic-calming strategies that offer opportunities for greening could help reduce environmental noise generated by road traffic. Ewing (1999) has proposed this hypothesis, but to our knowledge, no study has tested its validity. It would be relevant to carry out research for this purpose.

3.4 ACTIVE TRANSPORTATION

Land-use and road-network planning that prioritizes motor vehicle travel over active transportation (walking, cycling, etc.) encourages a sedentary lifestyle (WHO Regional Office for Europe, 2000). Although their position is certainly open to debate, the WHO goes so far as to suggest that the impact of traffic on active transportation constitutes its greatest negative impact on health (WHO Regional Office for Europe, 2000). It has been demonstrated that a sedentary lifestyle predisposes one to overweight and obesity, which increases, in particular, the risk of developing cardiovascular disease, certain cancers, type 2 diabetes, hypertension and certain mental illnesses (Centers for Disease Control and Prevention, 2010; Transport, Health and Environment Pan-European Programme, 2004; Desjardins, D'amours, Poissant, & Manseau, 2008). According to the data from 2005, 47% of Canadians are considered inactive, 35% of adults are overweight and 24% are obese (Human Resources and Skills Development Canada, 2011a; 2011b). In 1995, the number of premature deaths attributable to a sedentary lifestyle in Canada was estimated to be 21,000

(Katzmarzyk, Gledhill, & Shephard, 2000). In urban settings, a significant portion of car trips cover short distances,[22] and given favourable conditions, these trips could be made on foot or by bicycle, for example, thus contributing to more active lifestyles. Therefore, while traffic-calming strategies are primarily promoted as a way to reduce road collisions, injuries and deaths, they are also often proposed as a way to promote physical activity by helping create an environment that encourages active transportation, whether for utilitarian or recreational purposes.

3.4.1 Mechanisms of action

According to the studies consulted, traffic-calming strategies can influence the proportion of trips that involve active transportation (that is, the modal share) by means of four main mechanisms:

a) Improvement of perceived safety

Perceived danger from motorized traffic is identified in several articles as a major factor, if not the main factor, that discourages cycling (Pucher, Dill, & Handy, 2010; Pucher, Garrard, & Greaves, 2011; Reynolds, Harris, Teschke, Cripton, & Winters, 2009; Jacobsen, Racioppi, & Rutter, 2009; Pucher & Buehler, 2008). Concern about danger is more of a deterrent to children, the elderly and women, and thus contributes to health inequalities (Pucher et al., 2011; Jacobsen, 2003; Pucher & Buehler, 2008). The same concern also discourages people from walking (Jacobsen et al., 2009) and parents from letting their children walk or cycle to school (Direction de la santé publique, 2006). By thus deterring active transportation, perceived danger risks giving rise to a feedback loop (see Figure 22) in which perceived danger leads to a decrease in active travel, producing a concomitant increase in traffic volume, which in turn causes roads to be perceived as increasingly dangerous. By reducing traffic volumes and speeds, calming measures could help reverse this dynamic.

[22] Morency et al. (2007) estimate, for example, that in the Montréal metropolitan region, 11.7% (n=862,000) of trips carried out weekly cover distances of less than 1.6 km and that 55% of these are taken in motor vehicles. In the United States, according to the authors of one article, 41% of all trips carried out in urban settings cover distances of less than 3.2 km and 28% cover less than 1.6 km, with 89% of Americans using their car for trips of between 1.6 and 3.2 km and 66% for trips covering less than 1.6 km (Pucher & Renne, 2003). In Europe, according to WHO estimates, 30% of car trips cover distances of less than 3 km and 50% cover distances of less than 5 km (WHO Regional Office for Europe, 2011).

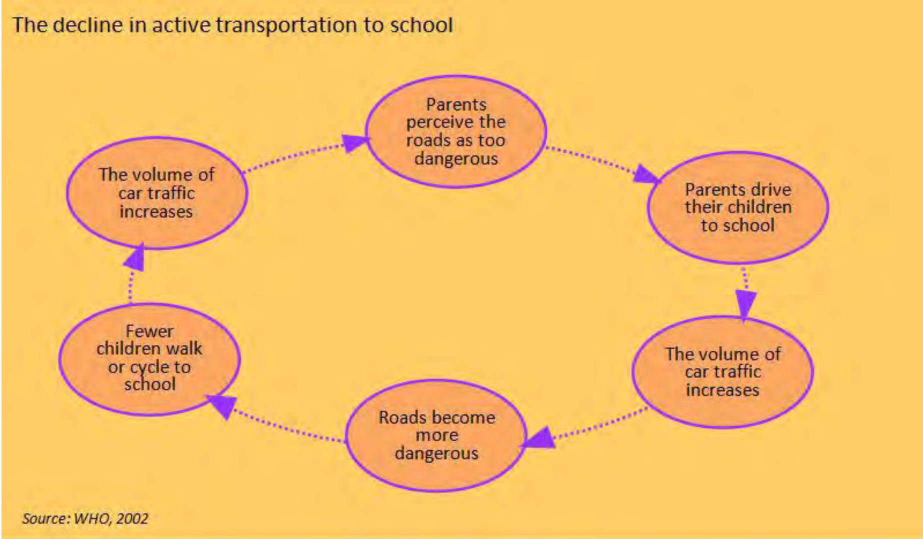

Figure 22 The vicious circle linking active transportation to perceived danger

Sources: Adapted from WHO Regional Office for Europe, 2002, p. 11, in Direction de la santé publique, 2006, p. 82.

b) Increase of the relative speed of active transportation

Reducing the gap between the speeds of motorized and active travel can make active travel for utilitarian purposes more attractive. According to the literature, traffic-calming strategies can reduce this gap in three main ways: 1) by slowing down traffic (Pucher et al., 2010); 2) by giving cyclists and pedestrians priority by installing facilities such as bike boxes, by synchronizing traffic lights with respect to cycling speeds, creating “green waves” for cyclists (Rietveld & Daniel, 2004) or by reserving exclusive traffic light phases for pedestrian crossing; 3) by providing coordinated networks of facilities designed for active transportation that reduce active travel distances and increase those of through traffic, as illustrated in Figure 23 (Bassett, Pucher, Buehler, Thompson, & Crouter, 2008; Pikora, Giles-Corti, Bull, Jamrozik, & Donovan, 2003; Pucher & Dijkstra, 2003).

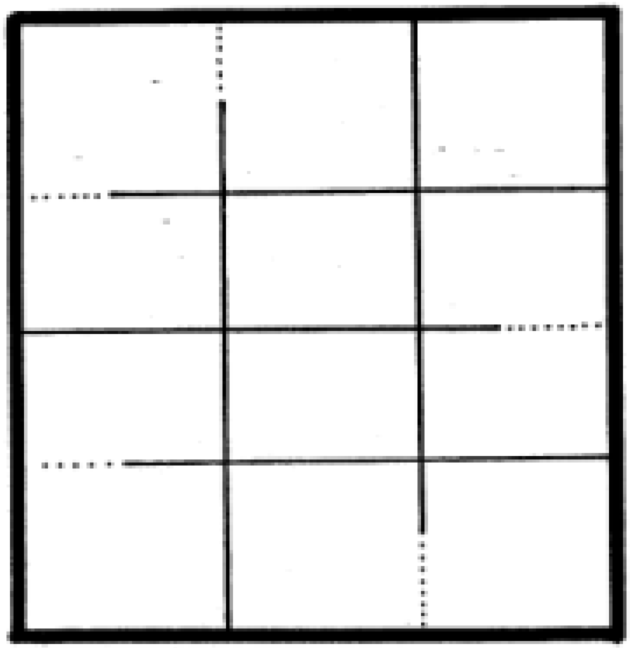

Figure 23 Diagram of a road network that is more permeable to active means of transportation than to motor vehicles

Dotted lines show routes restricted to active travel.
Source: Hummel, 2001, p. 30.

c) Reduction of perceived noise and atmospheric nuisances

Air and noise pollution caused by traffic can also deter people from walking or cycling by making active travel less pleasant (Jacobsen et al., 2009). If traffic-calming strategies succeed in reducing these irritants, they could encourage active travel.

d) Amelioration of aesthetics

Since the aesthetics of an area is one of the factors that determines the number of pedestrians and cyclists that go there (Pikora et al., 2003), a traffic-calming strategy designed to include high quality materials and to take advantage of the space recovered from motorized traffic by greening roads could also help increase active travel (TDM Encyclopedia, 2010b).

Most of the studies consulted that examine the effects of traffic-calming strategies on active transportation inferred these effects by referring to these four mechanisms without attempting to measure the effects. We have retained for purposes of analysis only those studies that evaluated the effects of one or of a series of calming measures. As in the preceding sections, we first present the data on isolated interventions installed at specific points on the road network or along a single street, followed by the data on area-wide calming schemes.

3.4.2 Effects of isolated traffic-calming measures

3.4.2.1 Objective studies

BOX 4 THEORETICAL LIMITATIONS OF ISOLATED INTERVENTIONS FOR ENCOURAGING ACTIVE TRANSPORTATION

Active transportation requires coordinated and interconnected networks on which it is possible and pleasant to travel quickly and safely to multiple destinations (Pucher & Buehler, 2008; Lee & Moudon, 2008). Except in the case where a network that is generally suitable for active transportation already exists and where isolated interventions would add missing connections or improve problem spots, it therefore seems unlikely, *a priori*, that isolated interventions could have as great an effect on the volume of active travel as area-wide strategies.

An article by Morrison et al. (2004) tabulates the number of pedestrians at three sites six months before and six months after the installation of a series of calming measures (five pairs of speed cushions, parking bays, and two zebra crossings) on the main road of a neighbourhood in Glasgow, Scotland. The authors note that a difference between the weather conditions during the first count (cloudy) and the second count (intermittent rain) may have led to an underestimation of the overall increase in pedestrian activity observed six months after the intervention. The presence of this confounding factor and the fact that only two one-day counts were carried out limit the significance of the results of this study. However, they are consistent with the self-reported significant increase in foot travel following the intervention (see below). Table 21 presents the results of the counts according to pedestrian age.

Table 21 Overall increase in the number of pedestrians following calming of a road

	Site 1 {CI 95%}	**Site 2** {CI 95%}	**Site 3** {CI 95%}
Children (0-16 years old)	+18.0%* {+15.4 to +20.6}	+44.1%* {+40.8 to +47.4}	+40.0%* {+2.8 to +9.0}
Adults (16-60 years old)	+12.3%* {+10.3 to +14.3}	+54.9%* {+52.2 to +57.6}	+11.4%* {+29.3 to +43.3}
Pensioner (60+ years old)	+5.9%* {+2.8 to +9.0}	+36.3%* {+29.3 to +43.3}	-53.8%* {-59.3 to -48.3}

* Significant variation at $p < 0.05$.

Source of the data: Morrison et al., 2004.

These results indicate a significant overall increase in pedestrian activity following calming of the road. The study does not explain the variation among the three sites and does not provide an explanation for the significant reduction in the number of pensioners walking observed at site 3.

3.4.2.2 Subjective studies

BOX 5 PARTICULAR IMPORTANCE OF SUBJECTIVE STUDIES TO UNDERSTANDING THE EFFECTS OF TRAFFIC CALMING ON ACTIVE TRANSPORTATION

The effect of calming strategies on active travel is dependent on the decisions of residents and road users who can choose to walk or cycle to destinations rather than use a motor vehicle. It also depends on the same people choosing to walk or cycle for recreational purposes. Since the desired effect is mediated by choice, it is likely to be influenced by the perceptions of residents and road users regarding, in particular, safety, amenability (aesthetics, air quality and ambient noise), and the time required to complete a utilitarian trip using active transportation (relative speeds).

The article by Morrison et al*.* (2004), presented in the previous section, also evaluates the perception of residents living on a road in Glasgow, Scotland, six months before and six months after the installation of calming measures (five pairs of speed cushions, parking bays, and two zebra crossings). Of the 750 residents randomly selected to fill out the postal questionnaire, 244 answered before the intervention and 185 answered afterwards. They were asked to evaluate their feelings about problems related to their environment, using a scale of 1 to 7 (1 being the happiest and 7 the unhappiest). Having compared the answers given before and after the intervention, the authors found significant improvements of 0.24 and 3.60 points in answers to the questions regarding safety for cyclists and drivers respectively and a non-significant improvement of 0.76 points for pedestrians. They also indicate a significant improvement of 2.19 points for questions regarding the ease of crossing the road and significant improvements of 2.88 and 2.83 points for air quality and environmental noise respectively. The improvement in feelings of safety and in the perceived ease of crossing the road, as well as the reduction of perceived nuisances, may have contributed to the significant increase in pedestrian activity observed six months after the intervention. The second questionnaire asked respondents to evaluate the changes in their travel behaviour that were attributable to the intervention. Table 22 presents the results reported in the article, which, however, does not indicate whether some residents reported or would have reported having travelled less by active means.

Table 22 Self-reported changes in the travel behaviour of residents of a calmed road

Travel behaviour	**{CI 95%}**
More walking	20.0%* {14.1 to 25.9}
More cycling	3.8%* {0.8 to 6.8}
Allowing children to play outside more	11.8%* {6.7 to 16.9}
Allowing children to walk more	12.5%* {7.2 to 17.8}
Allowing children to cycle more	11.6%* {6.6 to 16.6}

* Significant variation at $p < 0.05$.

Source of the data: Morrison et al., 2004.

The results of the second questionnaire seem to indicate that the significant increase in pedestrian activity observed on the road is due to an increase in active travel and not to increased use of the road resulting from decreased use of other roads. However, in the absence of data on those who reported or would have reported limiting their active travel, these results must be interpreted with caution. The article also reports a significant improvement in the self-reported physical health of residents six months after the intervention, but no significant change in their mental health.

Watkins (2000) gave a conference presentation on a study evaluating the perceived safety of residents of a street in Cambridge, Massachusetts (U.S.) on which curb extensions, a raised intersection, a pedestrian crossing and improved crosswalk markings had replaced traffic lights. It should be noted that the study indicates neither the sampling design used nor the number of respondents. The results, presented in Table 23, should therefore be interpreted with caution.

Table 23 Residents' perception of safety following calming of their street

	Better	Worse
Pedestrians	57%	13%
Cyclists	33%	8%
Motorists	46%	10%

Note: No statistical test for evaluating the significance of changes is mentioned.
Source of the data: Watkins, 2000.

The results indicate that more residents perceived an improvement in safety, for all types of road users, and in particular, for pedestrians and motorists. However, the study does not indicate whether these changes are significant.

Gibbard et al. (2004) produced a report for which they surveyed 393 relatively experienced cyclists using a questionnaire posted online on the websites of cycling associations based in England. The objective of the questionnaire was to determine how safe cyclists feel when they encounter calming measures involving road narrowing or horizontal deflection, such as chokers or curb extensions. Their results indicate that 78.4% of the cyclists who responded find these calming measures problematic, whereas only 17% are unaffected by them and 3.8% find them helpful. Many respondents said they stop at road narrowings (over 40%), that they sometimes move onto the sidewalk (46.8%) and that they sometimes choose another route to avoid them (48.6%). From among a list of phenomena resulting in road narrowings (various traffic-calming measures, parked vehicles, bus stops…), respondents identified pedestrian refuge islands or raised medians (38.9%), as well as chicanes (8.9%) as problematic. According to respondents, they perceive narrowings as dangerous because of the greater proximity of moving vehicles, especially heavy vehicles. Indeed, whereas only 5.3% of relatively experienced cyclists indicated feeling stressed or intimidated when negotiating this type of calming measure in the presence of motorcycles, this percentage rose to 33.6%, 46.6%, 59.8%, and 61.6% in the presence of cars, buses, light vans, and medium or heavy trucks, respectively. It should be noted that women indicated feeling more stressed or intimidated than men. Since it is often possible to adapt the configuration of calming measures to cyclists' needs, as shown by Figure 24, it would be relevant to determine if cyclists feel differently about narrowings or horizontal deflections that do not force them to go closer to motor vehicles. Unfortunately, the report does not allow for this distinction.

Figure 24 Two road narrowings configured differently

The choker on the left forces cyclists to come closer to moving vehicles, but the one on the right does not.

Sources: On the left, http://www.pedbikeimages.org. Photographer: Dan Burden. On the right, http://www.cyclestreets.net. Photographer: unknown.

3.4.2.3 Summary of results for isolated traffic-calming measures

The documentary search led to the identification of one article that had both objective and subjective dimensions (Morrison et al., 2004) belonging to the scientific literature, and two subjective studies (Watkins, 2000; Gibbard et al., 2004) drawn from the grey literature. These studies evaluate the effects of individual calming measures on the volume of active travel and the perceived safety of public road users. While their results converge, by themselves, these three studies have rather limited significance. The key points to recall are the following:

a) Increase in active transportation

One article (Morrison et al., 2004) reports a significant increase in the number of pedestrians using a calmed road and significantly more residents who reported walking or cycling more and letting their children play outside, walk, and cycle more, after the interventions.

b) Perceived safety

Two studies (Watkins, 2000; Morrison et al., 2004) indicate that the residents of calmed roads perceived an improvement in safety, for the various types of road users (drivers, cyclists and pedestrians), following the interventions. However, another study (Gibbard et al., 2004) reports that cyclists feel less safe in the presence of calming measures that introduce road narrowings or horizontal deflections forcing them closer to moving vehicles.

c) Promising calming measures

The studies consulted do not allow for a comparison of the effectiveness of isolated calming strategies at encouraging active transportation.

3.4.3 Effects of area-wide calming schemes

3.4.3.1 Objective studies

BOX 6 THEORETICAL ADVANTAGES OF AREA-WIDE INTERVENTIONS FOR ENCOURAGING ACTIVE TRANSPORTATION AND METHODOLOGICAL LIMITATIONS

A priori, area-wide strategies seem better adapted to influencing the volume of active travel than targeted interventions, because area-wide measures can contribute more to the establishment of coordinated and interconnected networks on which it is possible and pleasant to travel quickly and safely to multiple destinations. However, authors seeking to empirically evaluate the impact of area-wide calming strategies encounter, in particular, the following three methodological difficulties:

a) Threshold effects

Being dependent on coordinated and interconnected networks, the volume of active travel is likely to progress in accordance with the attainment of thresholds, with more significant increases achieved once a network reaches critical density and range, and not linearly, with each block of cycle track or each speed hump added, for example. This implies that evaluating a network being implemented in stages before it has reached a critical threshold could result in failure to measure an increase in active travel, even if the network were one step away from producing a significant increase in active travel (Pucher et al., 2010).

b) Synergies

One literature review concludes that the effect of various policies encouraging cycling depends on the synergies between them (Pucher et al., 2010). An area-wide strategy for calming traffic on residential streets coupled with the installation of cycle tracks on main arteries and bike parking facilities at various destinations, for example, is likely to have a much greater effect than the sum of each of these interventions taken separately. Based on 14 case studies, the literature review produced by Pucher et al. (2010) leads to the conclusion that the simultaneous presence of measures derived from a range of policies promoting cycling, which includes area-wide calming strategies, can considerably increase the volume of bicycle travel. However, methodologically it is difficult, if not impossible, to precisely determine the specific effect of an area-wide strategy in such a context, for it would be necessary to separate its effect from that of the other interventions, which likely produce their own effects, and also to measure the synergistic effects (Pucher et al., 2010).

c) Temporality

It is often the case that area-wide calming strategies are implemented gradually over a period of several years, especially when they extend over a large geographic area. This temporal dimension requires that evaluative studies be able to control for possible confounding factors (underlying trend, nearby interventions on the road network) over long periods of time.

The documentary search led to the identification of four studies having evaluated the effects of calming measures on geographic areas comprising more than one road. Only one of these focuses explicitly on calming measures that were systematically planned and implemented on a network of roads. This study is presented first. The three studies that do not specify the logic of the interventions examined are presented next.

Within the context of the report on Leigh Park (Cloke et al., 1999), interviews before (n=151) and after (n=150) the implementation of calming measures were carried out with groups of residents, in particular, to shed light on their travel behaviour. The report does not specify how the interviews were carried out or how participants were selected. Moreover, only 113 residents participated in the interviews both before and after the intervention. Due to these limitations, the results should be interpreted with caution. Table 24 summarizes the results of the survey according to the mode of travel used to reach various destinations.

Table 24 Modal share of residents' trips, by destination, before (n=151) and after (n=150) implementation of an area-wide calming strategy

	On foot		By bike		By bus[a]	
Destination	**Before**	**After**	**Before**	**After**	**Before**	**After**
Businesses	42%	27%	1%	1%	7%	11%
Work	6%	5%	1%	1%	1%	2%
Friends' homes	27%	18%	1%	0%	13%	15%

[a] Travel by bus is reported here because it has been shown that half of public transport users walk more than 19 minutes per day in the United States going to and from service points (Besser & Dannenberg, 2005), while public transport users in the Greater Montréal region perform, on average, 25% of the recommended amount of daily activity going to and from service points (Morency, Trépanier, & Demers, 2011).

Note: No statistical test for evaluating the significance of "before-after" differences is mentioned.

Source of the data: Cloke et al., 1999.

These results indicate a slight decrease in foot travel and a slight increase in travel by bus after the area was calmed.

One article (Carver, Timperio, & Crawford, 2008) evaluates the impact of the road environment on the physical activity of children (5 to 6 years old) and adolescents (10 to 12 years old) in Melbourne, Australia. The children (n=295) and adolescents (n=919) were recruited from 19 elementary schools. Parents were asked to report on the travel habits of their children and adolescents were asked to self-report. Moderate or vigorous physical activity outside of school hours was recorded using accelerometers. The road environment within an 800-metre radius of their homes was audited. The number of speed humps, the number of gateways (installed at the entrance to residential or calmed zones, for example) and the number of road narrowings, among other things, were determined and these were geocoded using a geographic information system (GIS). Multiple regression analyses were carried out to search for significant associations between elements of the road environment and (1) children and adolescents making at least seven walking or cycling trips per week and (2) moderate or vigorous physical activity. It should be noted that the choice of seven or more trips as a threshold could obscure the effects of the road environment on less frequent travel and that the article's analyses do not take into account the proximity of other facilities, such as parks or businesses. This said, the analyses did not reveal any significant associations between the presence of calming measures and (1) children making at least seven walking or cycling trips per week and (2) their level of physical activity. As regards adolescents, the presence of an average number of speed humps (2 to 7) was significantly associated (OR: 0.38, CI 95%: 0.15 to 0.97) with a decreased likelihood of boys making at least seven walking or cycling trips per week, whereas a high number of speed humps (8 to 99) was significantly associated (OR: 2.95, CI 95%: 1.34 to 6.51) with an increased likelihood of girls making as many trips. The number of speed humps present proved to be significantly and positively associated (r=0.210) with moderate to vigorous physical activity for boys during the evening, but negatively associated (r=-0.073) with physical activity for girls before school hours. As regards the number of road narrowings present, this was significantly and negatively associated (r=-5.197) with physical activity for boys during weekends.

Kamphuis et al. (2008) published an article evaluating potential significant associations between various characteristics of the road environment in Melbourne, Australia, and the recreational cycling behaviour of residents. Of the 4170 census collector districts less than 20 km from downtown Melbourne, 50 were randomly selected from samples stratified according to percentage of low-income homes. In each of these districts, covering an average area of 0.34 km^2, an audit was conducted of characteristics of the road environment within a 400 m radius of a randomly selected home. Based on the characteristics observed, three notable categories emerged: 1) traffic-calming measures influencing traffic speeds or volumes (e.g., speed humps); 2) crossing aids for pedestrians (e.g., raised medians, pedestrian refuges, curb extensions); 3) cycle tracks or bike lanes installed on roads. It should be noted that, referring to the examples provided in the article, it seems that calming measures that create horizontal deflections have been classified as crossing aids for pedestrians and calming measures that create vertical deflections have been referred to as calming measures. The article, however, does not explicitly make this distinction. It is also worth noting that, although cycle tracks or bike lanes may be introduced to calm traffic by narrowing roads (Macbeth, 1998), the article does not indicate why they were introduced or how they changed the road environment. Randomly selected residents (n=4005) of these districts were mailed a questionnaire asking whether they had cycled during the past month for recreational purposes. The responses from valid questionnaires (n=2203) and the results of the audit were analyzed using multilevel logistic regression models to identify significant associations. Calming measures were significantly and positively associated with recreational cycling (OR: 2.90, CI 95%: 1.19 to 7.02), as were cycle tracks and bike lanes (OR: 5.40, CI 95%: 1.29 to 22.60). As regards calming measures identified as crossing aids for pedestrians, no significant association was found (OR: 0.73, CI 95%: 0.30 to 1.78).

An article focused on walking behaviour and physical activity evaluates the influence of calming measures on the travel behaviour of residents of Minneapolis-St. Paul, in Minnesota, in the United States (Forsyth, Hearst, Oakes, & Schmitz, 2008). Using a sampling design stratified according to median street block length and residential density, 36 square areas of 805 x 805 m were randomly selected, and 715 residents of these areas were recruited for the study. Streets including at least one calming measure were identified in each of the areas studied, but the concept of traffic calming used in the article excluded devices that act on volume (e.g., forced-turn islands) as well as some measures that can affect road width (such as bike lanes). The travel behaviour of residents was measured for a period of seven days using accelerometers and self-completed travel diaries. The data gathered were analyzed using multilevel logistic regression. Positive significant associations were found between the percentage of street blocks with calming measures and (1) daily walking distances (r=0.3629) and (2) daily utilitarian walking distances (r=0.3674). No association was found involving recreational walking or physical activity in general.

3.4.3.2 Subjective studies

Within the context of the report on Leigh Park (Cloke et al., 1999), interviews before (n=151) and after (n=150) the implementation of calming measures were carried out with groups of residents, in particular, to determine their perception of the area. The report does not specify how the interviews were carried out or how participants were selected. Moreover, only 113 residents participated in the interviews both before and after installation of the calming measures. Due to these limitations, the results should be interpreted with caution. After the intervention, significantly fewer respondents reported being “very much” or “quite a lot” bothered by vehicles travelling at high speeds (83% before/55% after) or by traffic volumes (74% before/62% after). Also, significantly fewer respondents reported being “very much” or “quite a lot” bothered by the danger or difficulty of crossing the street on foot (81% before/57% after) or by the danger posed to children (93% before/70% after). However, the majority of respondents had perceived no change with respect to air quality (68%) or noise nuisances (58%) when out walking after the interventions. Even though the mechanisms identified at the beginning of the section would lead one to expect an increase in active transportation, the changes in residents’ perceptions did not produce an increase in the number of respondents who reported having opted for active transportation.

The report prepared by Hemsing & Forbes (2000) for the City of Ottawa and the Ottawa-Carleton region reports on residents’ perception of the safety of calmed roads and zones, according to the type of road on which they live (local, collector or artery) and the type of calming measure installed (horizontal, vertical or a combination of both). The survey was conducted using questionnaires distributed on a non-random basis to residents of already calmed roads. Thus, the representativeness of the sample cannot be affirmed, the less so since on some roads only a few surveys were filled out. For these reasons, the results should be interpreted with caution. Table 25 summarizes the views of residents, as reported in the report’s appendices, regarding the safety of pedestrians and cyclists following the interventions.

Table 25 Effects of an area-wide strategy on the safety of pedestrians and cyclists as perceived by residents

Calming measures	Types of roads	Safety of pedestrians crossing the street %			Safety of pedestrians walking on the sidewalk %			Safety of cyclists %		
		NC[a]	Incr.	Decr.	NC[a]	Incr.	Decr.	NC[a]	Incr.	Decr.
Horizontal	Local	31	48	14	34	43	17	**24**	**25**	**28**
	Collector	49	26	20	37	33	21	**19**	-	**45**
	Arterial	**32**	**25**	**29**	>50	27	23	-	-	**>50**
Vertical	Local	37	46	18	31	46	14	36	32	13
	Collector	36	29	24	**27**	**22**	**29**	34	-	24
	Arterial	25	62	-	25	56	12	-	49	15
Horizontal and vertical	Local	44	26	14	51	27	9	**27**	**16**	**24**
	Collector	-	-	-	-	-	-	-	-	-
	Arterial	32	45	13	37	39	9	**29**	**18**	**26**

[a] NC = "no change" perceived.

Note: No statistical significance test was mentioned, but the lines with underlined numbers indicate a greater proportion of respondents having perceived an increase ("Incr.") in safety, as opposed to a decrease ("Decr.") in safety; whereas the lines with bold numbers indicate the inverse relationship and those remaining in plain text indicate the inability to establish such a relationship.

Source of the data: Hemsing & Forbes, 2000.

Overall, it seems that more residents perceived an increase in pedestrian safety, than perceived a decrease in safety, whereas the inverse seems to be the case for cyclist safety. The report's appendices also contain information about residents' perceived changes in their travel behaviour. In general, residents did not think they had changed their travel behaviour.

3.4.3.3 Summary of results for area-wide calming schemes

The documentary search led to the identification of three articles (Carver et al., 2008; Kamphuis et al., 2008; Forsyth et al., 2008) belonging to the scientific literature, and two reports (Cloke et al., 1999; Hemsing et Forbes, 2000) drawn from the grey literature. These studies evaluate the effects of area-wide calming schemes on the volume of active travel and on public road users' perception of safety. By themselves, these studies have limited significance, in particular, because of their small number and their sometimes divergent results. The key points to recall are the following:

a) Variable effects on active transportation

One article reports that the presence of calming measures close to home is associated with a significant increase in recreational cycling (Kamphuis et al., 2008) and another (Forsyth et al., 2008) that it is associated with a significant increase in walking to utilitarian destinations, but that it is associated with neither a significant increase nor a significant decrease in recreational walking. A third article (Carver et al., 2008) reports that the presence of calming measures in the immediate environment of children (5-6 years old) is not significantly associated with their travel behaviour, but that significant positive and negative associations with the travel behaviour of adolescents boys and adolescent girls respectively can be observed. One study (Cloke et al., 1999) examining the implementation of an area-wide scheme reports a slight decrease in trips made on foot and a slight increase in trips made by bus, but no statistical significance tests accompany these results.

b) Variable effects on physical activity

One article (Carver et al., 2008) reports that the presence of calming measures in the immediate environment of children (5-6 years old) is not significantly associated with their level of physical activity, but that significant positive and negative associations with the levels of physical activity of adolescents boys and adolescent girls respectively can be observed. Despite having observed a significant positive association between the presence of calming measures near the home and utilitarian walking distances, another article (Forsyth et al., 2008) found no association with physical activity in general.

c) Variable effects on perceived safety

Two studies (Hemsing & Forbes, 2000; Cloke et al., 1999) report that residents of calmed areas perceive calmed roads as being safer for pedestrians. One of these (Cloke et al., 1999) also reports that children were thought to be safer on calmed roads, whereas the other (Hemsing & Forbes, 2000) indicates that cyclists were thought to be less safe. The study (Cloke et al., 1999) whose results are accompanied by statistical significance tests reports significant improvements after the interventions.

d) Promising area-wide strategies

The studies consulted do not allow for a comparison of the effectiveness of the various strategies for encouraging active transportation. Without providing conclusive evidence, one article (Kamphuis et al., 2008) nevertheless points to the benefits of using cycle tracks and bike lanes on roads to encourage bike travel. These measures can be used, among other things, to decrease the width of lanes devoted to motorized traffic (Macbeth, 1998).

3.4.4 Conclusion of the section on active transportation

3.4.4.1 Section summary

Although traffic-calming interventions are mainly promoted as a way of reducing the number of collisions, injuries and deaths, they are also frequently proposed as a way to encourage active transportation. However, although the mechanisms of action described support the logic of intervention, especially with regard to area-wide strategies, which can be designed to establish coordinated, safe and pleasant networks for walking or cycling travel, the methods and the rigorousness of the evaluative studies consulted, their number and their results do not support the conclusion that traffic-calming interventions encourage active transportation. Nevertheless, traffic calming seems to improve all road users' perception of safety, with the exception of cyclists, who report feeling less safe in the presence of certain calming measures (e.g., road narrowings). Since traffic calming, and in particular the area-wide approach, is usually integral to the policies of cities that have succeeded in increasing the modal share of public and active transportation and at decreasing that of cars (Pucher et al., 2010), it seems likely that the existing lack of evidence is partly due to the methodological difficulties described in Box 6.

3.4.4.2 Research gaps

Travel behaviour and perception

In general, more research is needed to better document the effects of traffic-calming interventions on travel behaviour and on the perception of various public road users.

Ideal strategy

According to Pucher & Buehler (2008), the ideal strategy for encouraging bike travel involves the calming of residential neighbourhoods in a manner that allows motor vehicles and cyclists to safely coexist, coupled with the installation of cycle tracks on arteries to separate drivers and cyclists. In light of certain European experiments that reflect this approach (in Amsterdam and in Copenhagen, in particular), this type of intervention seems promising; however, based on the results of the literature consulted, its effects on bike travel remain to be demonstrated.

Special needs of certain users

According to some authors (Bahar et al., 2009; Litman, 1999; Gibbard et al., 2004), certain calming measures, such as road narrowings and roundabouts, can prove problematic for some public road users, such as cyclists and visually-impaired pedestrians. For example, when encountering calming measures that narrow roads, cyclists may be forced closer to moving vehicles. Visually-impaired pedestrians, for their part, may find it difficult to find the right moment to cross a roundabout where the traffic is quasi continuous. The same authors suggest that these problems can usually be attributed to configurations of calming measures that do not take into account the needs of these users, whereas there exist alternative configurations worthy of consideration. Thus, it would be relevant to compare the effects of problematic configurations and of existing solutions on active transportation and on various users' perception of safety.

Inequalities

The area-wide approach to traffic calming often aims to redirect a portion of traffic on local streets toward the arterial network. Given that persons with low socioeconomic status tend to be overrepresented among residents of these roads (Smargiassi et al., 2006), it would be relevant to conduct research into the potential effects of area-wide strategies on inequalities linked to the travel behaviour of these persons.

4 CONCLUSION OF THE LITERATURE REVIEW

4.1 REVISITING THE WORKING PROPOSAL

The literature review was organized so as to allow for comparison of the effects on four health determinants of strategies based on the two approaches to traffic calming, implemented in an urban setting. In the introduction, we stated that area-wide strategies likely had more potential for improving population health than strategies based on the black-spots approach, because they favour interventions implemented on a larger geographic scale (networks comprising more than one street), they are often driven by broader objectives and goals (road safety and improvement of the living environment) and they tend to involve both the main mechanisms of action associated with calming measures (reduction of traffic speeds and of traffic volumes) rather than just one. A detailed examination of the relationship between the mechanisms of action and the health determinants being considered revealed another potential advantage of the area-wide approach. By intervening systematically in an area, they seem *a priori* better suited to encouraging driving at constant speeds in that area. The reduction of speed variations has, in turn, been identified as a transversal mechanism likely to simultaneously reduce collisions, air emissions and traffic noise, which, by acting on public road users' perceptions, is also likely to encourage active transportation. Thus, in theory, it seems that area-wide traffic-calming strategies that seek to reduce traffic volumes and encourage driving at low and constant speeds offer the most potential for improving population health.

As regards the evaluative studies consulted and analyzed, these allow one to conclude that, in general, traffic calming is an effective way to reduce the number of collisions, injuries and deaths. This holds true both for interventions that target high risk "black spots" and those that cover areas comprising more than one street. Probably because traffic calming is mainly promoted as a way to improve road safety, the literature examining this aspect is abundant and conclusive. While this is less true of the literature on the effects of traffic calming on air pollutant emissions and ambient air quality, the literature does indicate that calming measures, whether part of a black-spots or an area-wide approach, generally lead to an increase in per vehicle pollutant emissions, even though certain measures, such as mini-roundabouts, have more of a tendency to reduce them. However, the literature also indicates that area-wide strategies that reduce traffic volumes can compensate for an increase in per vehicle emissions or even reduce total emissions in the intervention area. Despite these increases and decreases in emissions, the studies do not report any significant variation in air quality in the vicinity of interventions, regardless of whether these are part of a black-spots or an area-wide strategy. As regards effects on nearby residents' perception of air quality, the results of studies are variable. With regard to the literature evaluating the effects of traffic calming on traffic noise, it is also less abundant and conclusive than that concerning road safety. Nevertheless, it indicates that the implementation of calming measures generally leads to a reduction in the maximum noise level of cars and an increase in that of heavy vehicles, regardless of whether the measures are part of an area-wide or a black-spots approach. Studies report more variable results concerning the effects of interventions on ambient noise levels and on nearby residents' perception of noise levels. As regards the effects of traffic calming on active transportation, the evaluative literature does not support the conclusion that either area-wide or isolated interventions encourage this, even though, in general, traffic calming seems to improve all road users' perceptions of safety, with the exception of cyclists, who report feeling less safe in the presence of certain calming measures (e.g., road narrowings).

While the mechanisms of action of the calming measures used in both strategic approaches seem to confer a theoretical advantage on the area-wide approach, it is important to stress that none of the studies consulted was specifically designed to measure and compare the effects of the two approaches to traffic calming. Within the current literature, only the results concerning the effects of traffic calming on one determinant, "air quality," allow for a direct comparison. With respect to this, it is possible to conclude that the area-wide approach, by reducing traffic volumes in an area, can effectively reduce total emissions produced there, whereas the black-spots approach has more of a tendency to increase total emissions, except when it involves the use of certain calming measures, such as mini-roundabouts. However, it must be recalled that the interventions evaluated were conducted in specific contexts and that not all their effects are known, not even all their effects on air quality. In fact, it is not known if the area-wide strategies evaluated simply shifted pollutants elsewhere along with diverted traffic, if they diverted traffic in a manner that reduces overall exposure to pollutants, or if they reduced absolute traffic volumes (by increasing the modal share of active transportation, for example). Thus, in general, the results of the evaluative studies do not lead to the unequivocal conclusion that one approach to traffic calming has more potential than the other to affect the four health determinants examined. On the other hand, the results do not call into question the logic underpinning the theoretical advantage of area-wide calming measures aimed at reducing traffic volumes and encouraging driving at low, constant speeds.

4.2 CONTRIBUTIONS AND LIMITATIONS OF THE LITERATURE REVIEW

The value of this literature review is threefold:

1) It makes it possible to predict, based on the mechanisms of action described and the results of the evaluative studies, the positive and negative effects on health determinants of certain combinations of calming measures (from the wide range available) and intervention contexts (e.g., replacement of traffic lights versus replacement of stop signs). These combinations serve as points of reference for the development of traffic-calming intervention strategies that promote health, at a time when this type of intervention in the built environment seems to be gaining in popularity in the country's large urban centres.
2) It brings together in a single document the principal mechanisms of action and the results of evaluative studies focused on the effects of the two broad approaches to traffic calming on four health determinants, whereas most synthesis documents do not distinguish between the two approaches and address only the number and severity of collisions.
3) It sets out the strengths and weaknesses of the existing literature on the effects of traffic-calming interventions on population health determinants.

Limitations:

1) The working proposal of the literature review made it necessary to classify the evaluative studies, which could not always be done on the basis of explicit references to the logic of interventions or on the basis of a detailed description of the traffic-calming interventions evaluated. Since the studies that failed to provide these details were not eliminated from the literature review, it is possible that some of them were misclassified.
2) To obtain an overview of the effects of traffic-calming interventions, instead of just studying the effects of individual interventions carried out in specific contexts, it was necessary to group together diverse interventions implemented in various contexts–which can make generalization hazardous.
3) The effects reported in this literature review apply to health determinants and do not correspond directly to effects on population health.
4) With only two exceptions (Zein et al., 1997; Hemsing & Forbes, 2000), the interventions evaluated by the studies examined in this literature review were implemented in countries other than Canada.

4.3 RESEARCH GAPS

In addition to the research gaps specific to each of the four health determinants covered in the literature review and described at the end of each section, certain factors would be worthy of study:

a) Canadian research

The vast majority of the empirical studies referred to in this literature review examine interventions implemented in European countries or in the United States. Only one article (Zein et al., 1997) and one report (Hemsing & Forbes, 2000) present evaluations of calming strategies implemented in Canada. Although these other countries were deemed sufficiently similar to Canada for the results of the studies to be applicable and relevant here, it would be interesting to see studies that document Canadian traffic-calming interventions, within their implementation contexts, and evaluate their effects.

b) Methodology

The majority of the empirical studies consulted sought to establish causal relationships between traffic-calming strategies and the four health determinants covered in this literature review. However, these causal relationships are often very complex. In fact, because the effects of strategies depend on the specific characteristics of interventions and their contexts, it is often difficult to establish, measure, and make generalizations about such relationships. Thus, there exists not only a need for evaluation methods adapted to these difficulties, but also for methods that can enhance understanding of the dynamic relationships between the built environment, the populations that live in it and their lifestyles (mode and frequency of travel, perception of facilities for walking and cycling and the safety of doing so, etc.) without reducing complex dynamics (co-determination of relationships, threshold and synergy effects, feedback loops) to linear causal relationships. Without proposing a method, the report by the Groupe de recherche Ville et mobilité (2008) on children using active travel to go to school provides an interesting example of research that sheds light on such dynamics by simultaneously examining the effectiveness of various interventions that promote active transportation, the evolution of policy and legal contexts that have either encouraged or discouraged the active travel of young Quebeckers, the system of actors closely or tangentially involved in how these children travel to school, and parents' perception of their children's mobility.

c) Accuracy of studies

Many of the studies consulted do not precisely describe the interventions evaluated (traffic-calming measures and strategies) and do not mention whether other interventions modified the environment at the same time (e.g., demand management policy) or if other relevant contextual changes may have taken place (e.g., increased fuel costs, recession, etc.). Future studies should attempt to clearly identify these relevant factors and to take them into account during data collection and analysis.

d) Temporality

Although several authors mention the importance of not evaluating the impact of an intervention immediately after implementation, so as to allow public road users time to adjust their behaviour to the new environment, none of the studies specifically documented the medium and long-term impacts of calming strategies on the four health determinants covered in this literature review. It would be relevant to research, for example, whether the effectiveness of calming strategies at reducing collisions and their severity tends to increase, decrease or remain the same after a certain number of months or years.

e) Policy context

Traffic-calming interventions fit within a context of diverse municipal policies which they may affect and which, inversely, may determine which interventions are favoured. It would be relevant to document how traffic-calming policies can fuel or impede other policies that have a positive or negative impact on health, as well as which municipal policies favour or impede the adoption of traffic-calming policies.

f) Citizen participation

In most cases, citizen participation constitutes an important component of the process of planning traffic-calming interventions (Ewing, 1999; TAC & CITE, 1998; Ewing & Brown, 2009). These processes are often initiated at the request of citizens or in response to their concerns about traffic volumes and speeds. Citizens are also frequently invited to play an active role in the planning of interventions by public authorities, who thus ensure the social acceptability of the calming measures selected. Such involvement by citizens can potentially make them feel more in control of their environment. Moreover, greater feelings of control have been associated with a decrease in the incidence and in the prevalence of numerous chronic diseases and mental illnesses (Paquet, Dubé, Gauvin, Kestens, & Daniel, 2010). It would be interesting to evaluate the positive, or even the negative, effects (in the case of significant community conflict, for example) on health of participative planning processes for traffic-calming interventions.

g) Social network

In the same vein, the protective effects of social networks on mental and physical health are relatively well documented (Holt-Lunstad, Smith, & Layton, 2010). Thus, just as citizen involvement in the process of planning interventions leads to social interaction and networking, so quieter, friendlier neighbourhoods that encourage walking and cycling can potentially increase the number of opportunities for social interaction (Leyden, 2003). It would therefore be relevant for studies to evaluate the potential of calming strategies to encourage the creation and strengthening of social relationships.

h) Heat islands

The literature review mentions several times the fact that the installation of calming measures, by recuperating urban space previously devoted to cars, offers opportunities for greening, which can have various desirable effects on noise, air quality and active transportation. Since plants can be used to combat the heat island effect (Shashua-Bar & Hoffman, 2000), it would be appropriate to evaluate the effect that the potential for greening created by traffic calming (when combined with other interventions) can have on urban heat islands.

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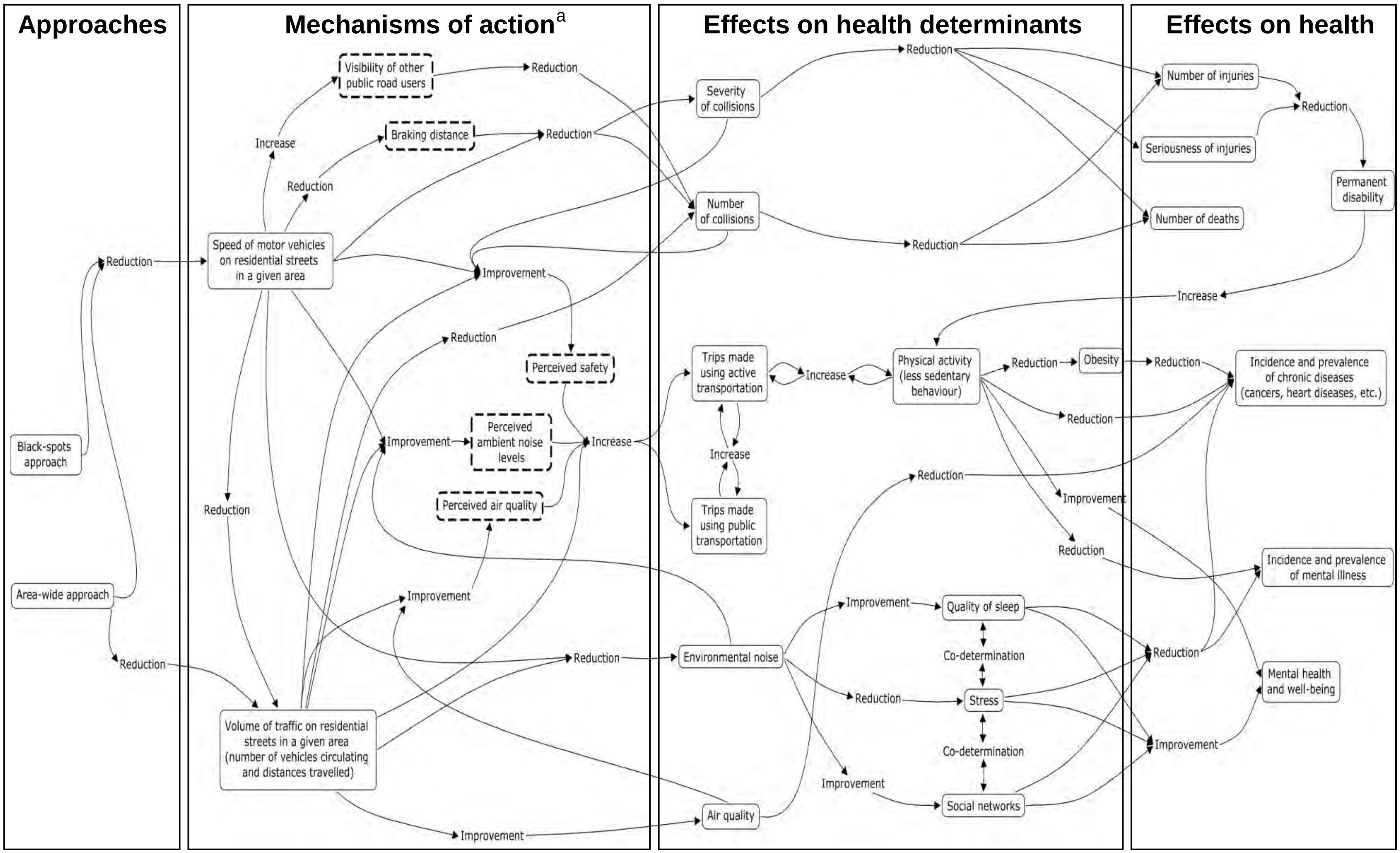
APPENDIX 1

INTERVENTION LOGIC OF THE TWO APPROACHES TO TRAFFIC CALMING

INTERVENTION LOGIC OF THE TWO APPROACHES TO TRAFFIC CALMING



[a] In this box, texts encircled by a solid line refer to the principal mechanisms of action of traffic-calming measures and strategies. Texts encircled by a broken line (dashes) indicate intermediate mechanisms acting between the principal mechanisms and the effects on the determinants of health.

APPENDIX 2

GLOSSARY OF TRAFFIC-CALMING MEASURES

GLOSSARY OF TRAFFIC-CALMING MEASURES

Bike box/ *Sas vélo, Sas cyclable*

A bike box is a facility that allows cyclists to position themselves in front of vehicles stopped at an intersection with traffic lights. This painted space on the pavement makes cyclists more visible and ensures them start-up priority when the light turns green.

Source: www.flickr.com.
Photographer: Richard Drdul.

Bike lane, Cycle lane/ *Bande cyclable*

A bike lane is a portion of the road reserved for the exclusive or preferential use of cyclists. Unlike a cycle track, which is physically separated from motor vehicles using the road, a bike lane is delimited by road markings. The space needed for the bike lane is generally obtained by eliminating one traffic lane, by narrowing one or several lanes, or by eliminating parking spaces for cars.

Source: www.pedbikeimages.org.
Photographer: Steven Faust.

Chicane, Serpentine, Reversing curve, Twist/ *Chicane*

A chicane is a series of horizontal deflections (usually three in a row) installed on an otherwise straight road to create an "S" shaped traffic lane.

Source: www.pedbikeimages.org.
Photographer: Dan Burden.

Choker, Mid-block narrowing, Pinch point, Mid-block yield point, Constriction/
Goulot d'étranglement

A choker is an isolated narrowing of one or several traffic lanes created by the installation of horizontal deflections in the centre or on the sides of the road. The term "choker," like its equivalents, is usually reserved for narrowings located other than at intersections.

Source: www.cyclestreets.net.
Photographer: unknown.

Crosswalk, Zebra crosswalk, Zebra crossing/
Passage piéton, Traverse piétonne, Traversée piétonne

A crosswalk is a facility designed to make crossing the road easier for pedestrians by delimiting a space with road markings to indicate that it is meant to be shared with pedestrians.

Source: www.pedbikeimages.org.
Photographer: Dan Burden.

Curb extension, Bulb-out, Bulbout/
Saillie de trottoir, Avancée de trottoir

A curb extension is a continuation of the sidewalk at an intersection intended to make pedestrians more visible and decrease their exposure to collisions by reducing crossing distances. A curb extension can also be used to reduce the width or the number of traffic lanes.

Source: www.flickr.com.
Photographer: Richard Drdul.

Cycle track/
Piste cyclable

A cycle track is a portion of the road reserved for the exclusive use of cyclists. Unlike a bike lane, which is delimited by road markings, a cycle track is physically separated from motorized traffic by bollards, medians, parking spaces, etc. The space needed for the cycle track is generally obtained by eliminating a traffic lane, by narrowing one or several lanes, or by eliminating parking spaces for cars.

Source: www.flickr.com.
Photographer: Eric Gilliland.

Diagonal diverters, Full diverters,
Diagonal road closures/
Terre-plein diagonal, Îlot diagonal

A diagonal diverter is a raised island placed diagonally at an intersection so as to allow only right turns. Diagonal diverters can be designed to allow pedestrians and cyclists to continue on their way unobstructed.

Source: www.flickr.com.
Photographer: UrbanGrammar.

Forced-turn island, Right-turn island,
Forced turn lane, Deflector island,
Forced turn channelization/
Îlot de canalisation, Îlot tourne-à-droite,
Îlot tourne-à-gauche

A forced-turn island is a median positioned at the approach to an intersection that orients vehicles in the desired direction or directions.

Source: Ewing, 1999, p. 29.

Full closure, Full street closure, Cul-de-sac, Dead-end/
Fermeture de rue, Impasse, Cul-de-sac

Full closures often take the form of barriers that prevent motor vehicles from continuing along the road, but allow pedestrians and cyclists to pass.

Source: www.pedbikeimages.org.
Photographer: Dan Burden.

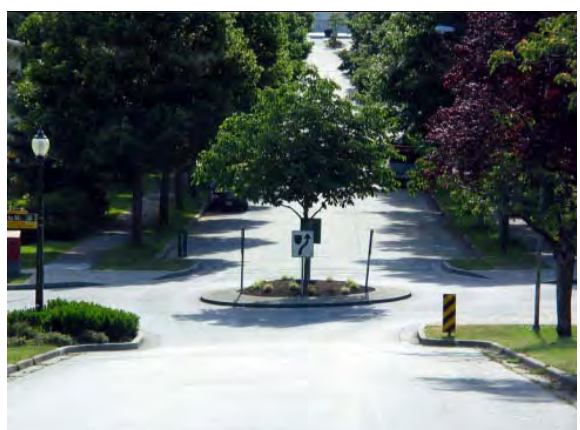
Gateway/
Portail d'entrée, Porte d'entrée

Gateways are facilities designed to indicate entrance to a calmed area.

Source: www.pedbikeimages.org.
Photographer: Dan Burden.

Mini-roundabout, Mini-traffic circles, Intersection islands/
Minigiratoire, Îlot circulaire

A mini-roundabout is an intersection with a central island that is usually raised and circular. Vehicles entering the circle must yield passage to those already inside and must travel around in a counterclockwise direction.



Source: www.pedbikeimages.org.
Photographer: Dan Burden.

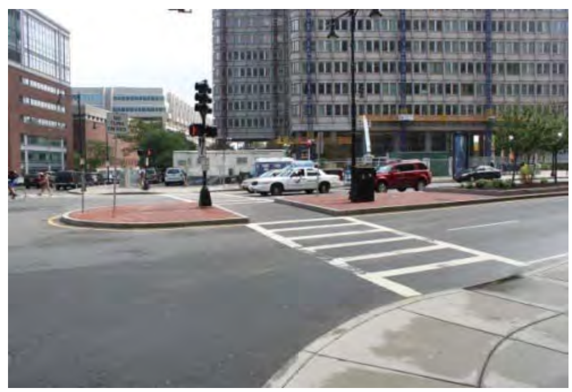
One-way street/ *Rue à sens unique*

A one-way street is a street on which vehicles are authorized to travel in only one direction. One-way streets can be used, with minimal cost, to prevent through traffic from using local residential streets instead of roads designed to handle larger traffic volumes (collector roads and arteries) to cross an area. For example, the installation of two facing one-way streets going in opposite directions can force drivers to turn onto an intersecting artery, and prevent vehicles from continuing in a straight line along local streets.

Source: www.flickr.com.
Photographer: Guillaume Goyette.

Pedestrian refuge, Median refuge/ *Refuge piéton*

A pedestrian refuge is a median typically located in the middle of the road to allow pedestrians to cross in two stages.



Source: NCCHPP.
Photographer: Olivier Bellefleur.

Raised crosswalk, Raised zebra crossing, Raised crossing, Hump pelican/
Passage piéton surélevé, Traverse piétonne surélevée, Traversée surélevée

A raised crosswalk is a facility designed to make crossing the road easier for pedestrians and which typically raises the pavement to the level of the sidewalks. Raised crosswalks are often made of a textured and coloured material to indicate clearly that the space is meant to be shared with pedestrians.

Source: www.pedbikeimages.org.
Photographer: Dan Burden.

Raised intersection, Raised junction, Intersection hump, Table, Plateau/
Intersection surélevée

A raised intersection is an intersection where the pavement has been raised relative to the level of the roads leading to it. The platform created by the vertical deflection is often made of a textured material and is raised to the level of the sidewalks to indicate clearly that the space is meant to be shared with pedestrians.

Source: www.cyclestreets.net.
Photographer: unknown.

Raised median, Centre island narrowing, Traffic island/
Terre-plein central, Îlot central

A raised median is a raised island usually built down the central axis of two-way roads to separate traffic going in opposite directions and reduce lane widths.

Source: www.pedbikeimages.org.
Photographer: Dan Burden.

Road diet, Lane reduction/ *Régime routier*

A road diet usually refers to the conversion of a four-lane road into a three-lane road, with one lane for traffic going in each direction and a central lane reserved for left turns from either direction. The space recuperated can be used to add bike lanes, sidewalks, or vegetation.

Source: www.pedbikeimages.org.
Photographer: Dan Burden.

Roundabout, Modern roundabout/ *Carrefour giratoire, Giratoire*

A roundabout is an intersection at which vehicles entering must yield right of way to vehicles already circulating around a central circular or oval-shaped island. To slow down traffic and induce drivers to yield right of way, there are horizontal deflections at the entrances which position vehicles to rotate in the correct direction. Roundabouts generally replace intersections with traffic signals on roads designed for quite high traffic volumes (collectors, arteries).

Source: www.flickr.com.
Photographer: WSDOT.

Speed bump, Bump/ *Dos d'âne*

Speed bumps, not to be confused with speed humps, are narrow vertical deflections that generally extend less than 30 centimetres across. In cars, it is easy to travel over them at very low speeds (5-10 km/h) or very high speeds, in which case the suspension system can absorb the deflection. Thus, their use is generally restricted to areas where high speeds are impractical, such as parking lots or alleyways.

Source: www.flickr.com.
Photographer: Bridget Ames.

Speed Camera/
Radar photo

Speed cameras are devices that allow vehicles exceeding the speed limit to be identified automatically.

Source: www.flickr.com.
Photographer: B.T. Indrelunas.

Speed cushions, Speed lumps/
Coussins berlinois

Speed cushions are vertical deflections designed to act on cars in the same way as speed humps, while having a minimal effect on heavy vehicles, such as emergency vehicles (fire truck, ambulance, etc.) and buses.

Source: www.flickr.com.
Photographer: Richard Drdul.

Speed hump, Road hump, Hump/
Dos d'âne allongé

Speed humps, not to be confused with speed bumps, are wide vertical deflections that typically extend three to four metres along the road. They can only be travelled over comfortably at low speeds (15-30 km/h). Thus, their use is widespread on local streets in residential neighbourhoods, in school zones, around parks, etc.

Source: www.pedbikeimages.org.
Photographer: Dan Burden.

Speed limit painted on the asphalt/
Marquage au sol indiquant la limite de vitesse

Road markings indicating the speed limit are often used in conjunction with other calming measures, such as vertical or horizontal deflections.

Source: www.flickr.com.
Photographer: Ian Britton.

Speed table, Trapezoidal hump, Speed platform/
Plateau ralentisseur

A speed table is a vertical deflection spanning the pavement, whose top is usually flat and extends far enough along the road for a car or even a heavy vehicle to rest on it. The vertical contour of speed tables allows them to be easily crossed at faster speeds than speed humps allow, which is why they are generally used on collector roads and arteries.

Source: Boulter et al., 2001, p.11.

Speed-activated sign/
Signal lumineux activé par la vitesse

A speed-activated sign is a device that usually indicates the speed of vehicles and whether they are travelling under or over the speed limit.

Source: www.flickr.com.
Photographer: Eric Allix Rogers.

Stop sign/
Panneau d'arrêt

A stop sign is a traffic sign indicating that drivers must stop their vehicle and wait until the lane is free before continuing on their way. Its purpose is usually to manage right of way for users of an intersection. However, it is also sometimes used as a traffic-calming measure. For example, stop signs have been used in the past to slow down traffic in certain areas, and thus make them less attractive to through traffic.

Source: www.flickr.com.
Photographer: Bridget Ames.

Textured crosswalk, Textured crossing/
Passage piéton texturé, Traverse piétonne texturée, Traversée texturée

A textured crosswalk is a facility designed to make crossing the road easier for pedestrians and which is made from a textured, and often coloured, material to indicate clearly that the space is meant to be shared with pedestrians.

Source: www.pedbikeimages.org.
Photographer: Richard Drdul.

APPENDIX 3

SUMMARY TABLES OF EVALUATIVE STUDIES

SUMMARY TABLES OF EVALUATIVE STUDIES

The tables below constitute a synthesis of the evaluations of traffic-calming interventions included in this literature review, including our comments. Readers will find here a synthesis of each study (research questions, methodology, results), along with a column containing remarks about the conceptual validity, the internal validity and/or the reliability of each one. Although they are presented individually, the studies are grouped into three broad intervention categories: those evaluating individual traffic-calming measures (when these are not explicitly identified as part of an area-wide intervention); those evaluating a series of measures installed on a single road; and those evaluating a series of measures in a geographic area including more than one road (whether they were planned to function in a systemic manner on a road network or were installed without an explicitly identified intervention logic[24]).

[24] It is arguable whether studies evaluating a series of measures contained within a given geographic area should be treated in the same manner as studies evaluating area-wide interventions when the intervention logic of the former has not been specified. To allow readers to interpret the information differently, an explanatory note has been included in the "Remarks" column to clearly identify such studies.

1 Evaluations of individual traffic-calming measures

AUTHOR (YEAR)	RESEARCH QUESTION[a]	METHODOLOGY	RESULTS[b]	REMARKS[c]
(Abbott et al., 1995)	How do maximum noise levels emitted by different types of vehicles on different types of roads maintained in different conditions vary? What effects do traffic-calming measures that vertically deflect vehicles have on traffic noise levels?	Design: experimental before-after study. Road types simulated in the London Transport Research Laboratory (U.K.) with narrow and wide speed cushions, speed humps, poorly-maintained and level roads. Vehicles tested: light (cars and milk trucks), buses and heavy vehicles (from 16 to 38 t). Maximum noise level measured at 7.5 m from road centre and at 1.2 m from ground (at a constant speed of 25 km/h and at constant speeds based on typical average speeds before and after installation of the traffic-calming measures tested) and modelling of sound levels (based on seven traffic composition scenarios).	<u>Maximum vehicle noise level</u>: At a constant speed of 25 km/h, the implementation of traffic-calming measures on a level roadway leads to fewer increases in maximum noise levels (in dB L_{Amax}) than road deterioration, for all types of vehicles. At typical constant speeds before and after the installation of traffic-calming measures, the introduction of vertical deflections has the following effect: reduces the average maximum noise level for light vehicles (-10.2 to -6.6Ŧ dB L_{Amax}); slightly increases (+1.0Ŧ dB L_{Amax} for narrow speed cushions) or lowers (-3.6 to -0.5Ŧ dB L_{Amax} for others) that of buses; increases that of heavy vehicles (+2.0 to +7.9Ŧ dB L_{Amax}), except in the presence of round-top humps (-2.1Ŧ dB L_{Amax}). <u>Noise levels</u>: Depending on the composition of traffic, the introduction of vertical deflections has the following effect on ambient noise conditions: improves it when there are only light vehicles (-7.1 to -4.8 dB L_{Aeq}Ŧ); improves it, has no effect, or worsens it (-1.3 to +7 dB L_{Aeq}Ŧ) when there are 10% heavy vehicles and 1% buses; worsens it (+0.1 to	Experimental fleet of heavy vehicles noisier than the average fleet in the country (overestimation of noise). Noise measurements based on typical constant speeds for each type of traffic-calming measure instead of taking into account speed variations caused by traffic-calming measures (risk of overestimating noise from suspension systems and rattling metal while underestimating acceleration and deceleration noise). No statistical significance test mentioned.

[a] The question or questions listed here are not necessarily isomorphic with those of the evaluations. When a study examined a broader subject than that of traffic calming, for example, the relationship between the built environment and physical activity, we formulated the questions such that they pertain to traffic calming.

[b] In general, when statistical significance tests are mentioned in the studies, only the significant results are reported here. Systematically, the term “significant,” as well as the “*” symbol are used to identify significant results of at least p <0.05. When non-significant results are reported, they are identified by the term “non-significant,” as well as by the absence of the “*” symbol. Results for which studies mention no statistical significance test are identified by the “Ŧ” symbol, and a comment is included in the “Remarks” column.

[c] The remarks included in this column concern the internal validity of the study and its reliability. Considerations related to external validity generally concern all the studies and are therefore addressed in the conclusion of the literature review.

1 Evaluations of individual traffic-calming measures (cont.)

AUTHOR (YEAR)	RESEARCH QUESTION	METHODOLOGY	RESULTS	REMARKS
(Abbott et al., 1995) (cont.)			+8.7 dB L_{Aeq}[Ŧ]) when there are 1% buses and 25% heavy vehicles. Narrow speed cushions and round-top humps would be preferable where heavy vehicles are present, because they would allow for decreased noise levels even in the presence of 94% cars, 1% buses and 5% heavy vehicles for narrow speed cushions, and of 79% cars, 20% heavy vehicles and 1% buses for round-top humps.	
(Boulter & Webster, 1997)	What are the effects of various traffic-calming measures and strategies on the emission of air pollutants by motor vehicles?	Design: traditional literature review. Data from 12 case studies (seven different countries) are reported and the interventions are briefly described. One case study concerns an intervention at a single point on a road network, six case studies examine the effects of introducing a series of measures on a road and five case studies concern area-wide interventions.	Effects on gas-powered cars of an intervention at a single point on a road network: • Speed hump, car with catalytic converter (WCC): +20%[Ŧ] Carbon monoxides (CO), +4%[Ŧ] Carbon dioxide (CO_2)/gas, +18%[Ŧ] Nitrogen oxides (NO_x); • Speed hump, car with no catalytic converter (NCC): +11%[Ŧ] CO, +5%[Ŧ] CO_2/gas, +22%[Ŧ] NO_x.	The methodology used to locate the case studies is not described. No statistical significance test mentioned.
(Campolieti & Bertoni, 2009)	What are the effects of replacing traffic lights with a roundabout on ambient noise levels in Modena (Italy)?	Design: before-after. Noise levels recorded by microphones located at three sites (two at the roundabout and one a few dozen metres away on a street leading to it).	Reduction of 1[Ŧ] dB L_{Aday} and of 2.5[Ŧ] L_{Anight}.	Controlled for volume and composition of motor traffic. Tables and calculations are somewhat obscure: data that would be needed to reproduce calculations on which conclusions are based are missing. No statistical significance test mentioned.

1 Evaluations of individual traffic-calming measures (cont.)

AUTHOR (YEAR)	RESEARCH QUESTION	METHODOLOGY	RESULTS	REMARKS
(Gibbard et al., 2004)	What are the effects on space sharing by motor vehicles, cyclists and pedestrians of traffic-calming measures that narrow roads at specific points and of measures for assisting cyclists at these points?	Design: (1) Internet survey, (2) before-after and after-only. (1) Survey by questionnaire between July 10, 2002 and August 13, 2002. Administered through the websites of cyclists' associations, so respondents were relatively experienced cyclists (n=393). (2) Analysis of conflicts between motor vehicles and cyclists at five sites where centre islands (raised medians) had been installed to provide a safe crossing point for pedestrians. A before-after study for two sites and after-only for the other three. Data on: number of cyclists; number of conflicts; whether or not motor vehicles slowed down; where vehicles overtook cyclists in relation to the road narrowing; distance between vehicles and cyclists; distance of cyclists from the curb. Sites with varying characteristics (for example, presence or absence of bike lane; regular bike lane vs. lane painted green). Daytime video survey (12 hours) for two days after (in all cases) and two days before (in two cases). Control for speed and volume of traffic.	(1) 78.4% of respondents indicated that the traffic-calming measures were problematic (because, according to them, they encourage motor vehicles to travel closer to cyclists); 17% said they were unaffected; 3.8% said the measures helped them. From among a list of phenomena resulting in road narrowings (various traffic-calming measures, parked vehicles, bus stops, etc.), respondents selected pedestrian refuge islands or raised medians (38.9%), as well as chicanes (8.9%) as problematic. Over 40% of respondents said they stopped at a road narrowing, 46.8% said they sometimes move onto the sidewalk at narrowings, and 48.6% indicated they sometimes choose another route to avoid narrowings. A few cyclists (5.3%) indicated feeling stressed or intimidated when negotiating this type of traffic-calming measure in the presence of motorcycles, but this percentage climbs to 33.6% when cars are present, 46.6% for buses, 59.8% for light vans, and 61.6% for medium or heavy trucks. Women indicated feeling more stressed or intimidated than men. (2) Cyclists appear to have a tendency to move closer to the curb when they are overtaken near a pedestrian island. The presence of a mandatory bike lane, without facilities allowing cyclists to bypass the narrowing, seems to encourage motor vehicle drivers to travel closer to cyclists. The presence of warning signs indicating an approaching island seems to prompt	(1) Experienced cyclists; mainly male (15.5% women, 84.5% men). (2) Two of the sites were part of area-wide schemes, although they were evaluated in isolation; the number of cyclists and conflicts observed was too low to produce statistically significant results.

1 Evaluations of individual traffic-calming measures (cont.)

AUTHOR (YEAR)	RESEARCH QUESTION	METHODOLOGY	RESULTS	REMARKS
(Gibbard et al., 2004) (cont.)			drivers to overtake cyclists before the island and to leave less space between themselves and cyclists when overtaking– except when the bike lane is painted green, which seems to prompt drivers to overtake cyclists after the island and to leave more room between their vehicles and cyclists. In areas where traffic was heavier and/or vehicles were sometimes parked along the edge of the road, cyclists tend to travel further from the curb as they pass through the road narrowing and drivers are less likely to overtake cyclists before or while passing through the narrowing.	
(Mountain et al., 2005)	What is the average effect of various speed management measures (speed cameras; vertical deflections; horizontal deflections and road narrowings and speed-activated signs) on collision frequency and vehicle speeds?	Design: before-after with control sites (empirical Bayes method: change in safety = expected number of collisions vs. number recorded). 79 sites with speed cameras; 31 sites using one or several horizontal deflections, road narrowings, speed activated signs (n=4) or speed limit painted on asphalt (n=1); 39 sites using vertical deflections (or a combination of vertical and horizontal deflections). Data from police and other local authorities on collisions, personal injury collisions (PICs) and collisions with persons killed or seriously injured (KSI). Data for 3 years before and, on average, 2.5 years after. Speed cameras: collisions recorded within a	Vertical deflections are more effective (-44%*, confidence interval [CI] 95%: -54 to -34) than horizontal deflections (-29%*, CI 95%: -48 to -8) and speed cameras (-22%*, CI 95%: -30 to -13) for reducing collisions. These reductions appear to correspond to reductions in average speed (vertical: -13.5 km/h*, CI 95%: -16.6 to -10.5; horizontal: -5.3 km/h*, CI 95%: -7.1 to -3.7; speed camera: -6.6 km/h*, CI 95%: -7.6 to -5.5). For KSI collisions, only vertical deflections produced significant reductions (-35%*, CI 95%: -54 to -18), whereas horizontal deflections (-14%, CI 95%: -44 to +32) and speed cameras (-11%, CI 95%: -26 to +6) produced non-significant reductions. For speed cameras and vertical deflections, respectively, -6%* (CI 95%: -9 to -3) and -6%* (CI 95%: -10 to -3) collisions are due to reduced traffic volume.	The grouping together of horizontal deflections and road narrowings with speed-activated signs (n=4) and markings indicating the speed limit (n=1) is unusual. The authors specify that they were grouped together because their results were similar. The inclusion of sites using vertical and horizontal deflections with sites using vertical deflections may obscure the specific effects of the combination. The analyses include control for regression to the mean only for total collisions. The article does not describe the implementation contexts of the traffic-calming measures evaluated. It is therefore impossible to

1 Evaluations of individual traffic-calming measures (cont.)

AUTHOR (YEAR)	RESEARCH QUESTION	METHODOLOGY	RESULTS	REMARKS
(Mountain et al., 2005) (cont.)		distance of 1 km upstream and 1 km downstream from the cameras.	Children, as cyclists and as pedestrians, as well as pedestrians, appear to benefit most from vertical and horizontal deflections. (The reductions concerning them are significant, but the results presented by type of road user do not take into account either regression to the mean or the underlying trend.) As regards the number of PICs avoided and not the percentage of reduction, speed cameras installed on high-volume roads registering a higher number of PICs allow for the avoidance of as many injuries (-1.00*/km/year, CI 95%: -1.4 to -0.6) as vertical deflections (-1.03*/km/year, CI 95%: -1.4 to -0.8) usually installed on local roads with lower traffic volume.	determine whether some of them were planned and implemented so as to function in a systemic manner within a road network.
(Retting et al., 2001)	What are the nature and the extent of reductions in collisions and their severity following the installation of modern roundabouts in the United States?	Design: before-after with control sites (empirical Bayes method: change in safety = expected number of collisions vs. number recorded). Analysis of data from police reports or, when these were unavailable, from report summaries concerning 24 modern roundabouts.	Reduction of 38%* in the total number of collisions (TCs), of 76%* in personal injury collisions (PICs) and of 89%* in fatal and incapacitating injury collisions (FIICs). Single-lane roundabout, in an urban environment, replacing stop signs: -61%* (TCs) and -77%* (PICs). Similar results in rural environments: -58%* (TCs) and -82%* (PICs). Multi-lane roundabouts, in an urban environment, replacing stop signs: -5% (TCs). Single-lane roundabout, in an urban environment, replacing traffic lights: -35%* (TCs) and -74%* (PICs).	Explanatory mechanism: reduced speeds and decrease in conflict points.

1 Evaluations of individual traffic-calming measures (cont.)

AUTHOR (YEAR)	**RESEARCH QUESTION**	**METHODOLOGY**	**RESULTS**	**REMARKS**
(Stout et al., 2006)	What are the effects on road safety of road diets (reduction from four to three lanes on bidirectional roads)? Do the two analysis methods used produce similar results?	Design: before-after with control sites and empirical Bayes method (change in safety = expected number of collisions vs. number recorded). Two methods using the same 15 experimental sites and 15 control sites: (1) Empirical Bayes Method. Analysis of monthly data from the Iowa Department of Transportation, for 23 years. (2) Before (5 years)-after (5 years) study with control sites.	(1) Reduction of 25.2%[‡] in the number of collisions per kilometre (collision density) and of 18.8%[‡] in the collision rate (controlled for volume) at the experimental sites, as compared to the control sites. (2) Reduction of 28%[‡] in the number of collisions per kilometre (collision density), of 21%[‡] in the collision rate (controlled for volume), of 34%[‡] for injury collisions, of 11%[‡] for fatal and serious collisions, of 30%[‡] for minor injury collisions and of 31%[‡] for possible injury collisions.	The expression “possible injury collisions” refers to collisions following which victims complained of pain, but where no other symptoms were visible. No statistical significance test mentioned.
(Tester et al., 2004)	How does living on a street block with a speed hump installed affect the probability that a child will be injured or killed by a car when walking close to home?	Design: observational case-control study. Use of admission data for a hospital emergency department in the city of Oakland (U.S.A.) over a period of five years (1995-2000). Identification of persons aged under 15 years (n=100) living on local streets who had been admitted after being struck by a car while walking near their home (radius of 0.4 km). Excluded were injuries caused by cars backing out of a driveway or a parking space. Each	Among control children, 23% (n=46) lived near a speed hump, whereas among case children, the rate was 14% (n=14). The matched-pairs analysis indicated that the probability that a child living near a speed hump will be injured by a car near home (radius of 0.4 km) and admitted to hospital is significantly lower (odds ratio [OR][d]: 0.50*, CI 95%: 0.27 to 0.89) than that of children not living near this kind of traffic-calming measure. When the analysis considers only those children injured on the street block where they live (n=49), the	The protective effect of speed humps within a radius of 0.4 km may depend on the proximity of other traffic-calming measures installed in the sector. However, the article does not indicate the implementation contexts of the speed humps studied. It is therefore impossible to determine whether some of them were planned and implemented so as to function in a systemic manner within a road network.

[d] OR or odds ratio: An odds ratio is a statistic produced through logistic regression that expresses the relationship between the probability that an event will occur and the probability that it will not occur. An odds ratio can be used to determine if, all other things being equal, persons living in an environment defined by certain characteristics are more or less likely to move around by bicycle, for example. An odds ratio of 1 would indicate that the characteristic had no effect, whereas a ratio of less than 1 would indicate that the characteristic in question lowers the likelihood that such persons would move around by bicycle and a ratio of more than 1 would indicate an increase in the likelihood. The further the odds ratio is from 1, the greater the effect on the probability of the event occurring.

1 Evaluations of individual traffic-calming measures (cont.)

AUTHOR (YEAR)	RESEARCH QUESTION	METHODOLOGY	RESULTS	REMARKS
(Tester et al., 2004) (cont.)		case patient was matched with two control children (admitted on the same day for other medical reasons, matched in terms of gender and age and also living on a local street). Case children and control children were classified into two categories: those living on a street block with at least one speed hump installed and those living on a street block without any speed humps. Matched-pairs analysis to determine whether proximity of speed humps is a significant risk reduction factor. Univariate analyses to determine whether other variables (race, ethnicity, household income and medical insurance) are also significantly associated. Multivariate analysis to isolate the effect of speed humps.	protective effect of speed humps is even greater (OR: 0.38*, CI 95%: 0.15 to 0.90). Univariate analyses indicated significant associations for the variables of ethnicity and race. The multivariate analysis (adjusted for ethnicity and race) indicated that the protection provided by proximity to a speed hump remains statistically significant and similar for children injured within a radius of 0.4 km (OR: 0.47*, CI 95%: 0.24 to 0.95), however, although the point estimate still indicates a protective effect, the confidence intervals indicate that the relationship is no longer statistically significant for children injured on the street block where they live (OR: 0.40, CI 95%: 0.15 to 1.06). On the basis of these results, the article concludes that speed humps make the environment safer for children walking.	

2 Evaluations of a series of traffic-calming measures implemented on one road

AUTHOR (YEAR)	RESEARCH QUESTION[a]	METHODOLOGY	RESULTS[b]	REMARKS[c]
(Ahn & Rakha, 2009)	What are the energy and environmental impacts of certain traffic-calming measures?	Design: before-after and cross-sectional. Study of behaviour on road network (and not on an experimental track) comparing: (1) at the intersections of a road: different traffic-calming measures (mini-roundabouts, speed humps, speed cushions), uncontrolled intersections and an intersection with stop signs; (2) on two other road sections: before and after the installation of five speed cushions on one road and two speed bumps on another. Combination of second-by-second GPS data (to capture variations in real speed) and microscopic energy and emission models. Different types of vehicles.	(1) Intersections with traffic-calming measures are associated with significantly greater gas consumption and higher emission levels than uncontrolled intersections and with significantly less consumption and lower emission levels than intersections with stop signs. (2) Traffic-calming measures significantly raise gas consumption and emission levels because they lead to variations in speed.	Data were collected on weekends to minimize interaction with other vehicles. (1) In comparisons of the traffic-calming measures at intersections, variations in emission levels on cross streets were not taken into account.

[a] The question or questions listed here are not necessarily isomorphic with those of the evaluations. When a study examined a broader subject than that of traffic calming, for example, the relationship between the built environment and physical activity, we formulated the questions such that they pertain to traffic calming.

[b] In general, when statistical significance tests are mentioned in the studies, only the significant results are reported here. Systematically, the term “significant,” as well as the “*” symbol are used to identify significant results of at least $p < 0.05$. When non-significant results are reported, they are identified by the term “non-significant,” as well as by the absence of the “*” symbol. Results for which studies mention no statistical significance test are identified by the “‡” symbol, and a comment is included in the “Remarks” column.

[c] The remarks included in this column concern the internal validity of the study and its reliability. Considerations related to external validity generally concern all the studies and are therefore addressed in the conclusion of the literature review.

2 Evaluations of a series of traffic-calming measures implemented on one road (cont.)

AUTHOR (YEAR)	RESEARCH QUESTION	METHODOLOGY	RESULTS	REMARKS
(Boulter & Webster, 1997)	What are the effects of various traffic-calming measures and strategies on the emission of air pollutants by motor vehicles?	Design: traditional literature review. Data from 12 case studies (seven different countries) are reported and the interventions are briefly described. One case study concerns an intervention at a single point on a road network, six case studies examine the effects of introducing a series of measures on a road and five case studies concern area-wide interventions.	Effects on gas-powered cars of a series of traffic-calming measures on a road: • Speed humps (SHs) with and without catalytic converter (CC): +70 to +80%[†] Carbon monoxides (CO), +70 to +100%[Ŧ] Hydrocarbons (HC), +50 to +60%[Ŧ] Carbon dioxide (CO_2)/gas, -20 to 0%[Ŧ] Nitrogen oxides (NO_x); • Ten SHs with CC: +300%[Ŧ] CO, +37%[†] CO_2/gas, +300%[Ŧ] NO_x; • Ten SHs without CC: +200%[Ŧ] CO, +51%[†] CO_2/gas, +300%[Ŧ] NO_x; • Various traffic-calming measures and 40-km/h speed limit: -9%[†] CO_2/gas; • Six SHs with CC: +300%[Ŧ] CO, +25%[†] CO_2/gas, +1000%[Ŧ] NO_x; • Five SHs: +36 to +73%[Ŧ] CO_2/gas; • Two roundabouts: +33%[Ŧ] CO_2/gas.	The methodology used to locate the case studies is not described. No statistical significance test mentioned.
(Boulter et al., 2001)	What are the effects of various traffic-calming measures (75 mm flat-top speed hump; 80 mm round-top speed hump; 100 mm raised intersection; 1.9 m and 1.7 m wide	Design: before-after and cross-sectional. Emissions: Evaluation based on the modelling of typical driving cycles before and after installation of traffic-calming measures on existing roads. Exceptions: for chicane, curb extension, mini-roundabout and speed cushions the data for modelling driving cycles before the interventions	Emissions: Average variations for all the traffic-calming measures taken together: Gas-powered cars NCC: +34%* CO, +50%* HC, +1% NO_x, +20%* CO_2; Gas-powered cars WCC: +59%* CO, +54%* HC, +8% NO_x, +26%* CO_2; Diesel-powered car: +39%* CO, +48%* HC, +28%* NO_x, +26%* CO_2, +30%* Particulate matter (PM).	The method used to model the typical speed profiles is not always made clear. For purposes of readability, steps that do not contribute to the final results because they were discarded and replaced by other procedures during the course of the experiment are not mentioned in the present document.

2 Evaluations of a series of traffic-calming measures implemented on one road (cont.)

AUTHOR (YEAR)	RESEARCH QUESTION	METHODOLOGY	RESULTS	REMARKS
(Boulter et al., 2001) (cont.)	speed cushions; chicane; curb extension; combination of bollards for narrowing a road and a speed cushion; mini-roundabout) on the emission of air pollutants by motor vehicles? What are the expected effects of these emissions on ambient air quality?	was taken from other roads with similar characteristics. Combinations of radar-type instruments to record drivers' speeds without their knowledge, counters to record traffic volume and video cameras to determine the composition of motor traffic on the selected road sections. Composition of sample speed profiles on the road sections under study and modelling of typical driving cycles. Measurement on a chassis dynamometer of emissions for three categories of cars as they drove through each of the typical driving cycles (12 gas-powered cars used, including 2 small cars with catalytic converters [WCC], 2 small cars with no catalytic converters [NCC], 2 medium cars WCC, 2 medium cars NCC, 2 large cars WCC, 2 large cars NCC and 3 medium diesel-powered cars). Air quality: Compiled emission data were analyzed using a dispersion model to determine effects at 10 m from road centres. The results take into consideration decreased traffic volume at one site and increases at four sites after installation (but the report does not specify when). The results also take into account the traffic volume of heavy vehicles, the emission data for which are taken from a previous study focused on the	Air quality: 1998: +0.9 to +8.0%[Ŧ] CO, +1.4 to +11.9%[Ŧ] benzene, +2.9 to +11.2%[Ŧ] 1,3-butadiene, -1.2 to +5.1%[Ŧ] NO_2; 2000: +0.4 to +6.7%[Ŧ] CO, +2.7 to +10.1%[Ŧ] benzene, +2.7 to +9.5%[Ŧ] 1,3-butadiene, -0.4 to +4.3%[Ŧ] NO_2; 2005: -0.5 to +5.1%[Ŧ] CO, +1.2 to +7.7%[Ŧ] benzene, +1.2 to +7.2%[Ŧ] 1,3-butadiene, +0.5 to +3.3%[Ŧ] NO_2.	The emission measurements based on the before and after speed profiles were not performed on the same cars. Seven of the twelve cars were replaced by other cars in the same category for the after tests. The results concerning air quality must be interpreted with caution because: (1) the report does not indicate when the before-after counts were taken. The authors imply that seasonal differences characterizing the before and after results or a general trend toward an increase in motorized travel can explain the increased traffic volume at four sites following the interventions. (2) No statistical significance test mentioned.

2 Evaluations of a series of traffic-calming measures implemented on one road (cont.)

AUTHOR (YEAR)	RESEARCH QUESTION	METHODOLOGY	RESULTS	REMARKS
(Boulter et al., 2001) (cont.)		relationship between the speed of these vehicles and their emissions. The effect is estimated for three years (1998, 2000 and 2005), based on the estimated proportion of vehicles with and without catalytic converters in England, but not based on the evolution of traffic volumes.		
(Daham et al., 2005)	What effect do speed humps have on the emission of air pollutants?	Design: experimental, aimed at simulating before-after measurements. Measurements made using a device installed on the automobile. On-road measurements of emissions were made on an existing road with an average of seven speed cushions/km. Control runs were made on the calmed road at a constant speed of 50 km/h. Experimental runs were made to simulate the presence of 80 mm speed humps (the highest); specifically, the vehicle was slowed down to 16 km/h and accelerated back up to 32-50 km/h in second gear at each speed cushion. Drive cycles tested: 1.1 km, roundtrip = 2.2 km, 14 speed cushions.	Substantial increase in emission of all pollutants measured: +90%[‡] CO_2; +117%[‡] CO; +195%[‡] NO_x; +148%[‡] HC.	It would not be cautious to use these results to characterize present or future emissions of air pollutants by vehicles travelling over speed humps or speed cushions because: (1) use of an exceptional driving style (the most aggressive) and presence of aggravating conditions (e.g., vehicles were very heavy due to the measurement equipment; vehicles were slowed down more than is necessary to simulate comfortably travelling over speed humps); (2) control runs on road with speed cushions instead of on road without calming measures and test runs over speed cushions instead of over speed humps; (3) no statistical significance test mentioned.

2 Evaluations of a series of traffic-calming measures implemented on one road (cont.)

AUTHOR (YEAR)	RESEARCH QUESTION	METHODOLOGY	RESULTS	REMARKS
(Morrison et al., 2004)	What are the effects on physical and mental health of the installation of several traffic-calming measures (five pairs of speed cushions, two zebra crossings, and parking bays) on the main road running through a disadvantaged residential area in Glasgow, UK?	Design: before (6 months)–after (6 months). Cohort of 750 participants recruited by random sampling (244 responded before and 185 after) to fill in postal questionnaires about their transport habits, their state of physical and mental health (SF-36 version 2), their perception of the neighbourhood, and of traffic problems and road safety. Two full-day pedestrian counts at three locations, with a one-year interval.	Significant increase in pedestrian activity. Perception: Significant reduction in traffic-related problems (e.g., parents allowing children to walk, cycle or play alone outside more, and less bothered by the speed of vehicles, fumes, noise, vibrations, etc. (refer to full table on p. 838 of the article). Significant improvement in self-reported state of physical health (note: no significant difference between those who reported walking more and the others). No significant effect on mental health.	Weak response rate (39% for the first questionnaire, once undelivered envelopes were taken into account, (244/624) and 32% for the second (185/576). The authors did not ask respondents if they had been unaffected or if they were walking or cycling less. The results of the pedestrian counts are congruent with the responses to the questionnaires with regard to physical activity, but these results are based solely on two one-day counts. The inclement weather for walking during the second count may have led to an underestimation of the increase in pedestrian activity.
(Watkins, 2000)	What are the effects of an intervention comprising several measures (curb extensions, raised pedestrian crossing, raised intersection and chicane) on a street in Cambridge, Massachusetts (USA)? How do residents perceive the impact on safety of an	Design: before-after and survey sent by post after. Measurement of percentage of drivers yielding to pedestrians before-after at a raised crossing and raised intersection. Survey by postal questionnaire between six and nine months after completion of construction work (perception of safety for various users of the street).	Drivers yielding to pedestrians: Raised crossing: 13% before, 53% after[‡]. Raised intersection: 18% before, 54% after[‡]. Perception of road safety: 69% better, 15% worse, 4% no change, 8% don't know. For pedestrians: 57% better and 13% worse. For cyclists: 33% better and 8% worse. For motorists: 46% better and 10% worse.	No statistical significance test mentioned.

2 Evaluations of a series of traffic-calming measures implemented on one road (cont.)

AUTHOR (YEAR)	RESEARCH QUESTION	METHODOLOGY	RESULTS	REMARKS
(Watkins, 2000) (cont.)	intervention comprising several measures (curb extensions, raised pedestrian crossing, raised intersection and improved crosswalk markings for pedestrians) replacing a traffic light.			

3 Evaluations of a series of traffic-calming measures implemented within a geographic area comprising more than one road

AUTHOR (YEAR)	RESEARCH QUESTION[a]	METHODOLOGY	RESULTS[b]	REMARKS[c]
(Boulter & Webster, 1997)	What are the effects of various traffic-calming measures and strategies on the emission of air pollutants by motor vehicles.	Design: traditional literature review. Data from 12 case studies (seven different countries) are reported and the interventions are briefly described. One case study concerns an intervention at a single point on a road network, six case studies examine the effects of introducing a series of measures on one road and five case studies concern area-wide interventions.	Effects of area-wide interventions on gas-powered cars: • Area with extensive traffic calming, without catalytic converter (CC): +7 to +71%[ǂ] Carbon monoxides (CO), -25 to -10%[ǂ] Hydrocarbons (HC), +7 to +19%[ǂ] Carbon dioxide (CO_2)/gas, -60 to -38%[ǂ] Nitrogen oxides (NO_x); • 30-km/h zone, without CC: -20 to +28%[ǂ] CO, -23 to +2%[ǂ] HC, -6 to +14%[ǂ] CO_2/gas, -31 to -5%[ǂ] NO_x; • Speed humps scheme: Slight increase[ǂ] CO, no change[ǂ] HC, decrease[ǂ] NO_x; • Area with extensive traffic calming: Increase[ǂ] CO, increase[ǂ] HC, decrease[ǂ] NO_x; • 21 mini-roundabouts and 30-km/h limit[d]: +2%[ǂ] CO, +<1%[ǂ] CO_2/gas, +1%[ǂ] NO_x.	The methodology used to locate the case studies is not described. No statistical significance test mentioned.

[a] The question or questions listed here are not necessarily isomorphic with those of the evaluations. When a study examined a broader subject than that of traffic calming, for example, the relationship between the built environment and physical activity, we formulated the questions such that they pertain to traffic calming.

[b] In general, when statistical significance tests are mentioned in the studies, only the significant results are reported here. Systematically, the term "significant," as well as the "*" symbol are used to identify significant results of at least p <0.05. When non-significant results are reported, they are identified by the term "non-significant," as well as by the absence of the "*" symbol. Results for which studies mention no statistical significance test are identified by the "ǂ" symbol, and a comment is included in the "Remarks" column.

[c] The remarks included in this column concern the internal validity of the study and its reliability. Considerations related to external validity generally concern all the studies and are therefore addressed in the conclusion of the literature review.

[d] Boulter and Webster (1997) classify this study among those evaluating cases of a series of calming measures installed on one road. However, the reference is to an evaluation of an area-wide scheme involving the installation of 21 mini-roundabouts in Växjö, Sweden, also evaluated by Hyden and Várhelyi (2000) and Várhelyi (2002). For this reason the study is included in this section.

3 Evaluations of a series of traffic-calming measures implemented within a geographic area comprising more than one road (cont.)

AUTHOR (YEAR)	RESEARCH QUESTION	METHODOLOGY	RESULTS	REMARKS
(Bunn et al., 2003)	Can area-wide interventions reduce road collision-related deaths and injuries?	Design: systematic review with meta-analysis. Inclusion of randomized trials and controlled before-after studies. Results pertain to 12 distinct controlled before-after studies evaluating a total of 16 area-wide strategies. Data collected from police or from "local authorities" on the number of collisions, fatal collisions and personal injury collisions. For each intervention evaluated, rate ratios were calculated for before/after/control zones.	Fatal collisions: Rate ratio (before/after/ control zones): 0.63 (confidence interval [CI] 95%: 0.14 to 2.59) or -37% (CI 95%: -86 to +159). Personal injury collisions (fatal and non-fatal): 0.89 (CI 95%: 0.80 to 1.00) or -11% (CI 95%: -20 to 0). Collisions: 0.95 (CI 95%: 0.81 to 1.11) or -5% (CI 95%: -19 to +11). Collisions involving a pedestrian: 1.00 (CI 95%: 0.84 to 1.18) or identical to the situation prior to the intervention (CI 95%: -16 to +18%).	The rates indicate a trend toward improvement, but the confidence intervals (CI) indicate that they are not statistically significant. Groups together evaluations of highly diverse area-wide interventions, which are only very briefly described (only the types of measures). The tests of heterogeneity between the results of different studies frequently proved statistically significant. A random effects model that pooled results was used to account for this heterogeneity. All the studies included focus on interventions carried out in the 1970s and 1980s. Having not controlled for exposure to risk, the authors suggest that there may possibly be more pedestrians in the calmed zones and that this would partially explain the absence of a reduction in collisions involving a pedestrian.
(Bunn et al., 2009)	Can area-wide interventions reduce road collision-related deaths and injuries?	Design: systematic review with meta-analysis. Update of the 2003 meta-analysis (Bunn et al., 2003): inclusion criteria modified to include "reduced speed limit zones." Results pertain to 18 distinct controlled before-after studies evaluating a total of 22 area-	Fatal collisions: Rate ratio (before/after/control zones): 0.79 (confidence interval [CI] 95%: 0.23 to 2.68) or -21% (CI 95%: -77 to +168). Personal injury collisions (fatal and non-fatal): 0.85* (CI 95%: 0.75 to 0.96) or -15%* (CI 95%: -25 to -4).	Same remarks as for 2003, except that the confidence intervals (CI) indicate that the reduction in personal injury collisions is statistically significant. The dates of the added interventions are not indicated.

3 Evaluations of a series of traffic-calming measures implemented within a geographic area comprising more than one road (cont.)

AUTHOR (YEAR)	RESEARCH QUESTION	METHODOLOGY	RESULTS	REMARKS
(Bunn et al., 2009) (cont.)		wide strategies.	Collisions: 0.89 (CI 95%: 0.76 to 1.05) or -11% (CI 95%: -24 to +5). Collisions involving a pedestrian: 1.01 (CI 95%: 0.88 to 1.16) or +1% (CI 95%: -12 to +16).	
(Carver et al., 2008)	What is the relationship between traffic-calming measures and active transportation for youth in Melbourne? What is the relationship between traffic-calming measures and physical activity for youth in Melbourne?	Design: cross-sectional study. Recruitment from 19 state primary schools in Melbourne (Australia) in areas of varying socioeconomic status (SES). Transport habits of young children (aged 5–6 years; n=295) reported by parents and self-reported by adolescents (aged 10–12 years; n=919). Moderate or vigorous physical activity outside of school hours recorded using accelerometers. Features of the road environment within a radius of 800 m around the home of each participant were identified using a geographic information system (GIS). Multiple regression analyses.	Adolescent boys in neighbourhoods with an average number of speed humps (from 2 to 7) are significantly less likely than those in neighbourhoods with a low number of speed humps (from 0 to 1) to make seven or more walking/cycling trips per week (odds ratio [OR]: 0.38*, confidence interval [CI] 95%: 0.15 to 0.97). However, adolescent girls in neighbourhoods with the most speed humps (from 8 to 99) are significantly more likely to make seven or more walking/cycling trips per week (OR: 2.95*, CI 95%: 1.34 to 6.51). The number of speed humps is significantly and positively associated with moderate to vigorous physical activity for adolescent boys during evenings (r=0.210*), but negatively with activity before school hours for adolescent girls (r=-0.073*). The number of road narrowings is significantly and negatively associated with physical activity for adolescent boys during weekends (r=-5.197*).	No significant association between the road environment and the likelihood of young children (aged 5-6 years) making seven or more walking/cycling trips per week. No significant association between the presence of traffic-calming measures and physical activity for young children. The article does not take into consideration the proximity of other features such as parks and businesses. In seeking associations between the road environment and seven or more walking/cycling trips per week, the authors may have missed other factors associated with fewer trips. This article evaluates the effects of traffic-calming measures on an area including more than one road, but it does not indicate whether or not the measures were planned and implemented so as to function in a systemic manner.

3 Evaluations of a series of traffic-calming measures implemented within a geographic area comprising more than one road (cont.)

AUTHOR (YEAR)	RESEARCH QUESTION	METHODOLOGY	RESULTS	REMARKS
(Cloke et al., 1999)	What are the effects of an area-wide strategy on collisions and injuries, on air quality and on noise? How are residents' perceptions affected? What are the effects on transport habits?	Design: before-after and before-after with control site. Evaluation of a traffic-calming scheme comprising various measures (raised intersection, speed cushions, pedestrian refuges, raised medians, curb extensions, mini-roundabouts, raised pedestrian crossings, gateways) aimed at reducing the speed of vehicles and at discouraging through traffic on residential streets in the Leigh Park area of Havant (UK). Collisions: Data for two 3-year periods before and for 20 months after. Air: For emissions, experimental analysis of driving cycles and modelling of HC, CO and NO_x. For air quality, diffusion tubes at six sites (including two control sites) to measure NO_2 and benzene. Noise: Analysis of noise levels (L_{Amax}, $L_{A10, 6h}$, $L_{A10, 18h}$, $L_{A90, 6h}$, $L_{A90, 18h}$) using the Statistical Pass-By method near three calming measures and residences. Video to determine vehicle types. Perceptions and transport habits: Interviews before and after of groups of residents selected among zones within the area to link results to the various measures.	Collisions and injuries: The number of personal injury collisions is stable 3 years before and 20 months after. No observable change involving motorcyclists, cyclists, and adult pedestrians, but a decrease of 50%ŧ per year in personal injury collisions involving child pedestrians. Air: Increase in emissions for most vehicles, but decrease for the area (due to the decrease in traffic volume). Non-significant improvement in air quality. Noise: In general, decrease in maximum noise level (L_{Amax}) of cars and increase in maximum noise level of heavy vehicles. Overall decrease in noise level exceeded 10% of the time during the day (-4.7 to -1.9ŧ dB LA10, 18h) and at night (-3.6 to -0.1ŧ dB LA10, 6h), except for noise at night at a pedestrian refuge (+2,6ŧ dB LA10, 18h). Mixed results with regard to background noise (LA90) during the day and significant increase at night (+7.8 to +14.1ŧ dB LA90, 6h), but doubtful validity. Perceptions: Perceptions vary from zone to zone. In general, significantly fewer persons bothered by speeding vehicles, the amount of traffic, danger or difficulty in crossing the road, or danger to children. Perceived improvement in road safety. Little effect on perception of other dimensions documented (noise, air pollution, etc.).	Air: No statistical test related to emissions is mentioned. Wide margin of error for instrument used to measure air quality. The measurements from the control sites neutralize the results. Noise: The results are based on only two days and two nights of recording. No control for weather variation. It is noted that the second night was very windy, which could explain the increase in background noise recorded. Perceptions: Significant methodological imprecision (the report does not specify how the interviews were carried out or how participants were chosen). The results are based on the responses of 151 residents before and 150 after, of which only 113 did both before and after interviews. These results should be interpreted with reserve.

3 Evaluations of a series of traffic-calming measures implemented within a geographic area comprising more than one road (cont.)

AUTHOR (YEAR)	RESEARCH QUESTION	METHODOLOGY	RESULTS	REMARKS
(Elvik, 2001)	What are the effects of area-wide schemes on road safety?	Design: systematic review with meta-analysis. Review of 33 studies (1971–1994) that provide information about numbers of collisions. Data on: design (all are before-after studies, with or without control sites–heterogeneity test of effects over time and across location [several countries] and of publication bias); traffic volumes; types of roads; personal injury collisions; number of collisions; property damage only collisions.	Travel habits: No notable effect. For the entire calmed area: -15%* (confidence interval [CI] 95%: -17 to -12) personal injury collisions; -16%* (CI 95%: -19 to -13) collisions without injury. For local roads in the calmed area: -24%* (CI 95%: -29 to -18) personal injury collisions; -29%* (CI 95%: -25 to -22) collisions without injury. For main roads in the calmed area: -8%* (CI 95%: -12 to -5) personal injury collisions; -11%* (CI 95%: -16 to -6) collisions without injury. Retaining only the studies with the most robust designs (before-after with control sites) recording personal injury collisions, only the reductions for the entire calmed area (-12%*, CI 95%: -21 to -1) are statistically significant.	The results of the studies are relatively consistent across decades and countries, which seems to indicate that the reported effectiveness is not the result of confounding factors, as these would have had to influence results in a consistent and uniform manner in varying implementation and evaluation contexts.
(Forsyth et al., 2008)	What is the relationship between walking and physical activity and certain characteristics of the built environment, including traffic-calming measures?	Design: cross-sectional study. Multilevel regression analysis to discern associations between over 200 environmental variables divided into four categories (density; street pattern or connectivity; pedestrian infrastructure and amenities [including calming measures]; and destinations) and walking and physical activity. Sample of 36 zones of 805 m x 805 m in Minneapolis-	Significant positive association between the percentage of calmed roads in an area (as well as the presence of sidewalks, street lights and several indicators of street connectivity) and both total walking distances (r=0.3674*) and transportation walking distances (r=0.3629*) covered by its residents, but no significant association with physical activity in general or leisure walking.	The concept of traffic-calming was operationalized in a restrictive manner that includes certain measures that can slow down motorized traffic. Excluded are measures acting on traffic volume and some that can influence speed by narrowing roads, such as bike lanes (Macbeth, 1998) (see online operationalization protocol www.designforhealth.net/pdfs/GIS_Protocols/NEAT_GIS_V5_0_26Nov2010FIN.pdf). Activity recorded from April to

3 Evaluations of a series of traffic-calming measures implemented within a geographic area comprising more than one road (cont.)

AUTHOR (YEAR)	RESEARCH QUESTION	METHODOLOGY	RESULTS	REMARKS
(Forsyth et al., 2008) (cont.)		St. Paul (USA) randomly selected among strata formed from pairings of median block size (small, medium, large) and residential density (low, medium, high). Random sampling of 715 participants, divided almost equally among the zones. Questionnaire focused on socioeconomic characteristics. Accelerometer and self-reported travel/walking diary. Environmental features measured through surveys and variables based on Geographic Information System (GIS) data from existing databases, interpretation of photos taken from satellites and a field-based urban design inventory.		November only. This article evaluates the effects of traffic-calming measures on an area including more than one road, but it does not indicate whether or not the measures were planned and implemented so as to function in a systemic manner.
(Grundy et al., 2008a)	What are the effects on inequalities in road traffic injuries of the 399 20-mph (32-km/h) zones in London (UK)? Note: In 2008, the percentage of roads covered by the zones varied by quintile (from 2.5% for Q1 [the	Design: longitudinal and cross-sectional study. Inequalities measured: Five levels of socioeconomic status (SES) based on the Index of Multiple Deprivation 2004 (data for 1987–2006) and on “ethnicity,” that is, white, black and Asian (data for 1996–2006). Personal injury collisions: Geocoded police data. Time series for intervention zones and adjacent areas. Calculation of the difference between the predicted	London-wide: Annual reductions were significantly greater in less-deprived SES quintiles for: personal injury collisions (PICs); child PICs; pedestrian PICs; cyclist PICs; powered two wheeler PICs; and car occupant PICs. Annual reductions were significantly greater among those identified as white than among Asian or black people for: PICs; child PICs; collisions with persons killed or seriously injured (KSI); pedestrian PICs; child pedestrian PICs; cyclist PICs; powered two wheeler PICs; and car occupant PICs. On the basis of a less	Controlled for the underlying downward trend in road injuries. Controlled for regression to the mean. Not controlled for underlying trend in road injury inequalities among ethnic groups; these results are therefore less reliable. The comparison among zones installed in areas with different SES was based on effectiveness expressed as a percentage, as is standard practice in the literature on this subject; it was not based on the number of injuries, of serious injuries,

3 Evaluations of a series of traffic-calming measures implemented within a geographic area comprising more than one road (cont.)

AUTHOR (YEAR)	RESEARCH QUESTION	METHODOLOGY	RESULTS	REMARKS
(Grundy et al., 2008a) (cont.)	least deprived] to 27.5% for Q5 [the most deprived]). In 2000 coverage was less than 2% for all quintiles. In terms of zones, 6% of zones were in Q1 and 35% in Q5 in 2008, whereas in 1995, 40% were located in Q1 and 10% in Q5.	outcome without intervention and the situation recorded in 2006. Thus, a longer or shorter time after the intervention, depending on the zone.	conservative risk reduction factor than that used in 2009 (Grundy et al., 2009), the authors conclude that having targeted deprived areas for installation of 20-mph (32-km/h) zones can be viewed as having prevented 1193 persons from being injured each year, with almost half of these being in the most deprived quintile. Regarding the number of injuries avoided, the installation of these zones can be viewed as having reduced the widening gap between PICs in the least deprived and the most deprived quintiles by about 15%[ǂ]. <u>Across 20-mph (32-km/h) zones</u>: Annual reductions (expressed as percentages) in PICs and KSI collisions are similar for zones and adjacent areas with varying SES, with the exception of powered two wheeler PICs and car occupant PICs, for which reductions are significantly higher in sectors adjacent to the most deprived areas. Annual reductions in PICs and KSI collisions in the zones and adjacent areas are similar for different ethnic groups. However, in calmed zones, significantly less reduction in KSI collisions, in pedestrian PICs and in child pedestrian PICs is observed among those identified in the study as black people than is seen among those identified as Asian or white.	and of deaths avoided. This practice is not without consequence for the results, for there are often more collisions, injuries and deaths in deprived areas than in the least deprived areas (Laflamme et al., 2010; Cubbin & Smith, 2002; Morency & Cloutier, 2005). Thus, it is likely that interventions whose effectiveness, expressed as a percentage, is the same for areas with different SES would prevent more collisions, injuries and deaths if they were implemented in areas with a lower SES. Use of a less conservative hypothesis than in 2009 (Grundy et al., 2009) to assess the number of injuries avoided.

3 Evaluations of a series of traffic-calming measures implemented within a geographic area comprising more than one road (cont.)

AUTHOR (YEAR)	RESEARCH QUESTION	METHODOLOGY	RESULTS	REMARKS
(Grundy et al., 2008b)	What are the effects on the number and seriousness of collisions of the 399 20-mph (32-km/h) zones that have been installed in London (UK) gradually since 1990?	Design: longitudinal and cross-sectional study. Description of interventions assisted by use of a geographic information system (GIS). Calmed zones range from a road segment of 0.07 km to one of 37 km (median: 3.6 km). Quantification of the effects of each zone on collisions and risk of injury (data collected by police) within the zones, on adjacent roads, and outside areas to verify whether collision “migration” occurred. Annual rates over 20-year period (1986–2006) used in main analyses. Time series analysis used to check for regression to the mean. Individual analysis of zones and pooled results. Calculation of the difference between the predicted outcome without intervention and the situation recorded in 2006 (thus, a longer or shorter time after the intervention, depending on the zone).	<u>General trend in London</u>: From over 50,000 (1987) personal injury collisions to a little over 30,000 (2006), with a plateau from 1993 to 2001. <u>Pooled data from zones</u>: Total collisions -37.5%* (confidence interval [CI] 95%: -43.4 to -31.6); personal injury collisions (PICs); -41.9%* (CI 95%: -47.8 to -36.0%); PICs involving children -48.5%* (CI 95%: -55.0 to -41.9); collisions with persons killed or seriously injured (KSI); -46.3%* (CI 95%: -54.1 to -38.6); KSI collisions involving children -50.2%* (CI 95%: -63.2 to -37.2); pedestrian PICs -32.4%* (CI 95%: -37.7 to -27.1); child pedestrian PICs -46.2%* (CI 95%: -55.5 to -36.8); pedestrian KSI -4.8%* (CI 95%: -47.5 to -22.1); child pedestrian KSI -43.9%* (CI 95%: -61.3 to -26.6); cyclist PICs -16.9%* (CI 95%: -29.0 to -4.8); cyclist KSI -37.6%* (CI 95%: -60.9 to -14.4); powered two wheeler PICs -32.6%* (CI 95%: -43.4 to -21.7); powered two wheeler KSI -39.1%* (CI 95%: -59.1 to -19.0); car occupant[e] PICs -52.5%* (IC 95%: -62.4 to -42.5); car occupant KSI -61.8%* (CI 95%: -71.7 to -52.0). <u>Adjacent areas</u>: All collisions -7.4%* (CI 95%: -11.0 to -3.8); PICs -8.0%* (CI 95%: -11.5 to -4.4); KSI collisions -7.9%* (CI 95%: -13.5 to -2.2); car occupant PICs -11.5%* (CI 95%: -16.5 to -6.4).	There appears to be no significant difference between the large calmed zones (more than 3.6 km of road) and the small calmed zones (3.6 km and less) as regards the effectiveness of reducing personal injury collisions and collisions with persons killed or seriously injured. Having not controlled for exposure to risk in their analyses, the authors suggest that there may possibly be more pedestrians in the calmed zones and that this would partially explain the smaller reduction in collisions involving pedestrians. No migration of collisions was observed, but the results do not take into account measures that may have been taken to calm traffic on adjacent roads. Thus, the authors may overestimate the effectiveness of 20-mph (32-km/h) zones in reducing collisions on these roads. Data one year before and one year after presented in the body of the text, but up to five years before and five years after included in appendices (note: little difference between the two).

[e] Occupants include drivers and passengers of automobiles.

3 Evaluations of a series of traffic-calming measures implemented within a geographic area comprising more than one road (cont.)

AUTHOR (YEAR)	RESEARCH QUESTION	METHODOLOGY	RESULTS	REMARKS
(Grundy et al., 2009)	What are the effects of 399 20-mph (32-km/h) zones on the number of collisions causing minor injury, serious injury and death in London (UK)?	Design: longitudinal and cross-sectional study. Observational study of geocoded police data (1986-2006) covering 119,029 road segments with at least one collision (out of a total of 298,644 segments included in the database). Estimation of the effects in the area where the zones where introduced and on adjacent areas and adjustment for underlying downward trend.	Condensed form of the 2008 report; thus, results are the same (Grundy et al., 2008b). Result added for personal injury collisions involving child cyclists (0–15 years): -27%* (confidence interval [CI] 95%: -49.1 to -6.3). On the basis of a more conservative risk reduction factor than that used in 2008 (Grundy et al., 2008a), the authors estimate that the 20-mph (32-km/h) zones in London prevent 203 persons, including 51 pedestrians from being injured each year, and that, of these, 27 would have been seriously injured or killed.	Controlled for regression to the mean: little effect. Controlled for location of zones (city centre vs. periphery): no effect.
(Hemsing & Forbes, 2000)	What do residents and road users perceive to be the effects of traffic-calming measures on walking and cycling safety, on air quality, and on noise levels in Ottawa[f]?	Design: survey and interview afterward. Survey by questionnaire. Comments from public during public hearings. Interviews with individuals, organizations and special interest groups. Results were pooled according to the categories of calmed roads (local, collector, regional) and the type of traffic-calming measures installed (vertical, horizontal, vertical and horizontal).	Perception of air quality: The majority of respondents observed no change or did not know if there had been one. For most road categories, more respondents perceived an improvement than deterioration. Perception of environmental noise levels: The majority of respondents observed no change or did not know if there had been one. For most road categories, more respondents perceived an increase in noise levels than a decrease.	Non-random survey. Thus, there is a risk that it may not be representative of "the population" of Ottawa. On some roads, only a few surveys were filled out. No statistical significance test mentioned. The extrapolation of the results should therefore be interpreted with caution.

[f] The report covers numerous other dimensions that could very well have been the subject of our literature review, such as the perceived effects of traffic calming on social cohesion, for example. However, this is the only study we found that examines these other dimensions. Given that the results concerning these dimensions are not in themselves conclusive, we decided not to review them. As regards air quality, environmental noise levels, and transport habits, there exists a body of literature which, although not very extensive, is at least sufficiently large to allow for analysis. This is why we have included these dimensions in the literature review.

3 Evaluations of a series of traffic-calming measures implemented within a geographic area comprising more than one road (cont.)

AUTHOR (YEAR)	RESEARCH QUESTION	METHODOLOGY	RESULTS	REMARKS
(Hemsing & Forbes, 2000) (cont.)	Have residents been walking and cycling more since the interventions?		Perception of pedestrian and cyclist safety: Overall, more residents perceived an increase in pedestrian safety and a decrease in cyclist safety. Travel habits: In general, residents did not think they had changed their habits.	
(Hyden & Várhelyi, 2000)	What are the effects of an experimental scheme involving the installation of 21 mini-roundabouts (at intersections whose daily volume can go as high as 23,500 vehicles) in Växjö, Sweden, on the risk of personal injury collisions, on yielding, on CO and NO_x emissions and on noise levels?	Design: before-after. Several measurements before (four months) and after (four months for all and a follow-up four years later for four of the 21 mini-roundabouts). Measurements of speed, conflicts (at 12 intersections), videotapes, road user counts, interviews with pedestrians. Note: The calculation of emissions is discussed in detail in Várhelyi (2002). The same results are reported.	Conflict study: Stable total, car-car increase, car-bicycle and car-pedestrian decrease. Less serious conflicts (from frontal to angular and at lower speeds). Estimated number of personal injury collisions: -44%[Ŧ] (cyclists: -60%[Ŧ], pedestrians: -80%[Ŧ], drivers: +12%[Ŧ]). Note: one of the mini-roundabouts produced an increase in the risk of personal injury collisions of +200%[Ŧ] at one intersection. At a four-year follow-up, one mini-roundabout, whose centre island had been enlarged, was found to have complicated the route of cyclists. Yielding: More respect for the priority of other drivers (70% before and 91% after)[Ŧ], of cyclists (13% before and 77% after)[Ŧ] and of pedestrians (24% before and 51% after)[Ŧ].	The article points to the importance of design in the construction of traffic-calming measures and in the evaluation of effects (one of the mini-roundabouts, whose construction differed from that of the other mini-roundabouts included in this comparison study, was found to have increased the risk of personal injury collisions by about 200%[Ŧ]). The anomaly represented by this roundabout also reduced the positive effects on conflicts. The very small number of pedestrians questioned regarding their perception of the ease of crossing makes it necessary to interpret these results with caution.

3 Evaluations of a series of traffic-calming measures implemented within a geographic area comprising more than one road (cont.)

AUTHOR (YEAR)	RESEARCH QUESTION	METHODOLOGY	RESULTS	REMARKS
(Hyden & Várhelyi, 2000) (cont.)	What was the perceived effect on ease of crossing for pedestrians?		Emissions: See Várhelyi (2002). Noise: Reduction of 3.9ǂ, 4.2ǂ and 1.6ǂ dB L_{Aeq} for the three intersections studied. Perception: Of the 26 pedestrians questioned four years later, 40% found that crossing was easier at mini-roundabouts than at other intersections and 20% found it more difficult.	
(Jones et al., 2005)	Does the distribution of traffic-calming measures reflect social and economic inequalities? Are they related to personal injury collision rates for child pedestrians?	Design: Ecological study of small area of intervention (two cities in the UK). Longitudinal analysis of injury rates with cross-sectional control for modes of travel to school. Participants: Sampling of children aged 4 to 16 years old between 1992 and 2000. Indicators: Distribution of interventions/socioeconomic status of areas and changes in personal injury collision rates/1000 residents (police data).	City A: Areas in the most deprived fourth had 4.8* (confidence interval [CI] 95%: 3.71 to 6.22) times the number of traffic-calming measures/1000 residents as those in the most affluent fourth. The personal injury collision rate for the whole city decreased from 6.98 to 4.84 between 1992–1994 and 1998–2000, which corresponds to a significant decrease of 2.14* (CI 95%: -2.81 to -1.48). In the most affluent areas, the rate went from 9.53 to 5.85, which corresponds to a significant reduction of 3.68* (CI 95%: -5.28 to -2.13). The rate for the most deprived areas went from 3.21* (CI 95% 2.27 to 4.54) times that of the most affluent areas to 2.01* (CI 95%: 1.45 to 2.87), which corresponds to a non-significant reduction in inequalities. City B: Areas in the most deprived fourth	The audit of measures was limited to speed humps, road narrowings, and road closures. The article does not provide information about similarities or differences between road networks in the most and least deprived areas (often the most affluent areas are already calmed, for example by grids made up of cul-de-sacs, a possibility here, given the significant differences in the length of road networks in the most and least deprived areas, particularly in city A). This article evaluates the effects of traffic-calming measures on an area including more than one road, but it does not indicate whether or not the measures were planned and

3 Evaluations of a series of traffic-calming measures implemented within a geographic area comprising more than one road (cont.)

AUTHOR (YEAR)	RESEARCH QUESTION	METHODOLOGY	RESULTS	REMARKS
(Jones et al., 2005) (cont.)			had 1.88* (CI 95%: 1.46 to 2.42) times the number of traffic-calming measures/1000 residents as those in the most affluent fourth. The personal injury collision rate did not vary significantly between 1992-1994 and 1998–2000 and inequalities were not reduced significantly, the rate for the most deprived areas having gone from 4.27* (CI 95%: 2.51 to 7.28) times that of the most affluent areas to 3.96* (CI 95%: 2.26 to 6.95). Variations in the personal injury collision rates are inversely correlated to the density of traffic-calming measures (n.b. of traffic-calming measures/km of road) (r=-0.769*, p=0.026). Similar proportions of children walked to school in both cities.	implemented so as to function in a systemic manner.
(Kamphuis et al., 2008)	How are individual and environmental characteristics (including traffic-calming measures) associated with area socioeconomic inequalities in the Melbourne region (Australia) and between-area	Design: cross-sectional study. Measurement of the practice of cycling for recreational purposes: at least once a month vs. never. Survey by postal questionnaire on cycling habits and individual characteristics (age, sex, education, occupation); 2349 participants, 2203 valid questionnaires. Environmental audits using a Geographic Information System (GIS) for some environmental	Traffic-calming measures are one of the four characteristics of road design that are significantly associated with recreational cycling (odds ratio [OR]: 2.90*, confidence interval [CI] 95%: 1.19 to 7.02). Bike paths and lanes on roads, which can be used to calm traffic, are another (OR: 5.40*, CI 95%: 1.29 to 22.60).	Bike paths and lanes can be introduced as traffic-calming measures (Macbeth, 1998). This article does not indicate why they were introduced or how they modified the road environment (e.g., by narrowing the road). Also, some traffic-calming measures (e.g., curb extensions) were classified under “safety” as “crossing aids,” which excludes them from the analysis of traffic-calming measures (considered alone, this category

3 Evaluations of a series of traffic-calming measures implemented within a geographic area comprising more than one road (cont.)

AUTHOR (YEAR)	RESEARCH QUESTION	METHODOLOGY	RESULTS	REMARKS
(Kamphuis et al., 2008) (cont.)	differences in recreational cycling?	characteristics (road network design [includes some calming measures], safety [includes other calming measures], destinations, and aesthetics). Analysis using multilevel logistic regression.		produces no significant association, but it could be otherwise were it combined with other characteristics classified as “calming” features). This article evaluates the effects of traffic-calming measures on an area including more than one road, but it does not indicate whether or not the measures were planned and implemented so as to function in a systemic manner.
(Owen, 2005)	What are the effects on air quality of six 20-mph (32-km/h) zones implemented in North West England?	Design: before-after study with control site. The article considered 0.5 km x 0.5 km zones with signs and traffic-calming measures that modified road design (e.g., speed humps). Concentrations of NO_2 and benzene measured before (5 to 9 months) and after (3 to 12 months) at three sites within each zone and at one outside control site. Use of diffusion tubes and thermal desorption tubes. Analysis of standard deviation and temporal variation. Vehicle emissions (NO_x and benzene) estimated on the basis of average speeds and traffic volumes.	Ambient concentrations of air pollutants measured were not significantly affected by the interventions. For the five zones for which calculations were performed, emissions per vehicle rose (0 to +5%[Ŧ] NO_x, +11 to +34%[Ŧ] benzene), but when variations in traffic volume were taken into account, emissions were shown to have decreased in the majority of zones (+8, -18, -9 , -32 and -80%[Ŧ] NO_x; +22, +3, -15, -32 and -76%[Ŧ] benzene). The dispersion model indicates that the contribution of traffic within the zone to the ambient concentrations of air pollutants measured is weak (4 to 14%[Ŧ] of NO_x; 0 to 3%[Ŧ] of NO_2).	Controlled for background concentrations and weather. Controlled for traffic volumes, but use of average speeds instead of real speeds (thus eliminating the effect of speed variations). Imprecision of instruments measuring air quality (±25% for the diffusion tubes).

3 Evaluations of a series of traffic-calming measures implemented within a geographic area comprising more than one road (cont.)

AUTHOR (YEAR)	RESEARCH QUESTION	METHODOLOGY	RESULTS	REMARKS
(Owen, 2005) (cont.)		Use of a dispersion model to determine the contribution of traffic in the zone to ambient concentrations of air pollutants.		
(Várhelyi, 2002)	What are the effects of an experimental scheme involving the installation of 21 mini-roundabouts (at intersections whose daily volume can go as high as 23,500 vehicles) in Växjö, Sweden, on gas consumption and CO and NO_x emissions?	Design: before-after. Recording of driving cycles before (n=600) and after (n=800) the installation of mini-roundabouts to construct standard driving cycles. Vehicles were selected randomly and followed by a car equipped to record distance travelled twice per second. The driver of the car with the measuring equipment copied the movements of the other drivers without their knowledge. Traffic counting performed with automatic counters and manually. Model used to calculate gas consumption and emissions.	At the 20 mini-roundabouts replacing intersections without traffic lights: significant increase in CO (+13%*) and non-significant increase in NO_x (+8%) and gas (+8%) for users of main roads, and non-significant decrease for those using secondary roads (-20% CO, -15% NO_x, -21% gas). Combined, the mini-roundabouts produced a non-significant increase in emissions (+6% CO and +4% NO_x) and gas consumption (+3%). With regard to the mini-roundabout replacing an intersection with traffic lights, non-significant reductions in emissions and gas consumption were calculated (-29% CO, -21% NO_x, -28% gas). No significant change in traffic volume.	The article points to the importance of the implementation context of interventions (e.g., is an intersection with or without traffic lights being replaced?) and the varying potential effects at intersections (main road vs. secondary road). Calculations were limited to gas-powered cars, despite the fact that heavy vehicles comprised 7% of traffic. Calculations were based on the assumption that 30% of cars were equipped with catalytic converters. Only one statistically significant result. The article does not indicate precisely when, with respect to the installation of the mini-roundabouts, the effects were measured.
(Zein et al., 1997)	What effects do traffic-calming schemes have on the frequency and severity of collisions?	Design: before-after. Four areas in the Greater Vancouver and Victoria regions were examined. The interventions are described with the help of maps showing the types and locations of measures. Before-after study (the authors reviewed data for one year before the	The four interventions reduced the frequency of collisions (-40%[Ŧ] on average) and the annual cost of collisions (-38%[Ŧ] on average).These averages obscure marked differences between the interventions (for example, a stop-sign scheme in Burnaby and a scheme involving highly diverse physical measures in the West End area),	This article does not meet recognized scientific standards. In particular, it provides very little information about data sources and about the years being compared, which makes it impossible to reproduce and compare the measured reductions in general trends.

3 Evaluations of a series of traffic-calming measures implemented within a geographic area comprising more than one road (cont.)

AUTHOR (YEAR)	RESEARCH QUESTION	METHODOLOGY	RESULTS	REMARKS
(Zein et al., 1997) (cont.)		interventions and collected data following the intervention, but without indicating when). Indicators: collision frequency (police data) and collision severity (annual costs of insurance claims according to the Insurance Corporation of British Columbia).	significant differences between areas (for example, -18%[Ŧ] for collision frequency in West End, Vancouver, and -60%[Ŧ] in Burnaby) and between indicators (in Burnaby, -60%[Ŧ] for collision frequency and -48%[Ŧ] for claims costs).	However, the interventions are very well described and the level of detail provided in the analysis tables makes the results more informative than many studies meeting the recognized scientific standards.

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