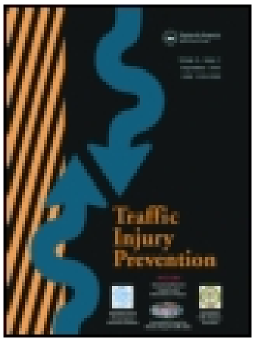

Traffic Injury Prevention

ISSN: 1538-9588 (Print) 1538-957X (Online) Journal homepage: http://www.tandfonline.com/loi/gcpi20

Do Light Truck Vehicles (LTV) Impose Greater Risk of Pedestrian Injury Than Passenger Cars? A Meta-analysis and Systematic Review

E. Desapriya , S. Subzwari , D. Sasges , A. Basic , A. Alidina , K. Turcotte & I. Pike

Traffic Injury Prevention, 11:48–56, 2010

ISSN: 1538-9588 print / 1538-957X online
DOI: 10.1080/15389580903390623

Do Light Truck Vehicles (LTV) Impose Greater Risk of Pedestrian Injury Than Passenger Cars? A Meta-analysis and Systematic Review

E. DESAPRIYA,[1,2] S. SUBZWARI,[1] D. SASGES,[3] A. BASIC,[1] A. ALIDINA,[1]
K. TURCOTTE,[1] and I. PIKE[1,2]

[1]BC Injury Research and Prevention Unit, Developmental Neurosciences and Child Health: Neurons to Neighbourhoods, Formerly Centre for Community Child Health Research, BC Children's Hospital, Vancouver, British Columbia, Canada
[2]Department of Paediatrics, BC Children's Hospital, Vancouver, British Columbia, Canada
[3]Faculty of Medicine, University of Toronto, Toronto, Ontario, Canada

Objective: *Pedestrian crashes present a growing challenge for public health trauma and road safety researchers around the world. They are associated with substantial morbidity, mortality, and cost, yet there is an international lack of published work on the topic, especially when compared with vehicle occupant safety studies. Our review attempts to quantify the risk of fatal injury among vulnerable road users. The specific objective of this systematic review and meta-analysis is to quantify and compare the impact of light truck vehicles (LTVs) versus conventional cars on pedestrian fatal injury.*

Methods: *A protocol was developed using methods of the Cochrane Collaboration. We conducted a search for the studies in bibliographic databases that included ATI (Australian Transport Index); Cochrane Injuries Group Specialized Register; EMBASE; ERIC; MEDLINE; National Research Register; PsycINFO; Road Res (ARRB); SIGLE; Science (and Social Science) Citation Index; TRANSPORT (NTIS, TRIS, TRANSDOC, IRRD). Web sites of traffic and road accident research bodies, government agencies, and injury prevention organizations were searched for grey literature. Reference lists from selected papers or topic reviews were scanned for potentially relevant papers.*

Results: *Our initial search identified 878 potentially eligible studies. After thorough review by three of the researchers a total of 12 studies were included in the systematic review, 11 of which were included in the meta-analysis. The overall pooled odds ratio for the risk of fatal injury in pedestrian collisions with LTVs compared to conventional cars was odds ratio 1.54, 95 percent confidence interval 1.15–1.93, $p = 0.001$. Thus, the risk for pedestrians of sustaining fatal injury is 50 percent greater in collisions with LTVs than in collisions with conventional cars.*

Conclusions: *Our systematic review and meta-analysis suggests that LTVs pose a greater risk of pedestrian injury death compared to conventional cars. These findings have important implications for the automotive industry and the safety of vulnerable road users.*

Keywords Pedestrian fatal injury crashes; Light truck vehicles; Greater mass; Increased stiffness; Bumper height; Front design modifications

INTRODUCTION

Road traffic crashes are a major cause of death and disability worldwide. It is estimated that by 2020, road traffic crashes will be the third leading cause of disability adjusted life years (DALY) worldwide and the second leading cause of DALYs in rapidly motorizing countries (Murray and Lopez 1997a). The World Health Organization predicts that road traffic crashes will become the third leading cause of mortality in the near future (Krug et al. 2000; Murray and Lopez 1997b). Pedestrian crashes present a growing challenge for public health trauma and road safety researchers around the world (Desapriya et al. 2006; Mohan 2002). Annually, there are an estimated 1.2 million pedestrian road deaths and 50 million injuries, more than 85 percent of which occur in developing countries (Krug 1999; Peden et al. 2004). Unfortunately, it is predicted that pedestrian road deaths will increase by 65 percent in the next 10 years (Peden et al. 2004). Pedestrian crashes are associated with substantial morbidity, mortality, and cost, but there is an international lack of published work on the topic, especially compared to vehicle occupant related studies (Simms and O'Neill 2005). A recent

Received 29 May 2009; accepted 6 October 2009.
No author has a financial or proprietary interest in any material or method mentioned.
Address correspondence to: Dr. Ediriweera Desapriya, Developmental Neurosciences and Child Health: Neurons to Neighbourhoods, Formerly Centre for Community Child Health Research, L408-4480 Oak St., Vancouver, BC V6H 3V4, Canada. E-mail: edesap@cw.bc.ca

United Nations resolution encouraged Member States to continue using the *World Report on Road Traffic Injury Prevention* (Peden et al. 2004) as a framework for road safety efforts and implementing its recommendations by paying particular attention to the needs of vulnerable road users such as pedestrians.

Unfortunately, recent changes in the composition of the global vehicle fleet may mean even greater threat to pedestrians. Over the past 10 years, there has been an extraordinary explosion in the popularity and purchase of larger vehicles, such as light truck vehicles (LTVs). LTVs are defined as any vehicle with the body on frame construction historically found on trucks. This category includes minivans, pickup trucks, and sport utility vehicles (SUVs), also called 4 × 4s. Further, LTVs are designed to appeal to the buyer's self-image, many of them evoking an impression of speed, power, esteem, and maximum safety to their occupants. Such impressions conflict and jeopardize safety and the needs of pedestrians and other vulnerable road users. In the United States, 40 percent of new vehicles purchased fall under this classification. A recent report shows that in last decade alone about 36 million SUVs were sold in the United States (Lieber and Bernard 2008). In Europe in 2004, sales of SUVs increased by 15 percent, whereas sales of smaller passenger cars dropped by 4 percent (Simms and O'Neill 2005). It is estimated that globally, in both developed and underdeveloped countries, LTVs make up 30 percent of vehicles found on the road. In Chile, LTVs make up 25 percent of the top-selling vehicles. In South Africa, there has been a threefold increase in LTV popularity since 2001. In India, there was a 50 percent increase in LTV sales in 2003 alone (Dandona 2005).

White (2004) used a random sample of all police-reported motor vehicle crashes to demonstrate that when collision occurs, light trucks impose significant externalities on other cars, trucks, and pedestrians. Importantly, the results of this study suggest that a 1 percentage point increase in the light truck share of the vehicle fleet increases annual traffic fatalities by approximately 0.34 percent, or 143 deaths per year. One recent study in Japan showed that LTVs are significantly increasing the fatality risk in crashes (Sekine at al. 2008).

LTVs differ from cars in three key areas: they have greater mass and increased stiffness and the bumper is much higher off the ground. These factors change the anatomy of a pedestrian-involved collision (Crandall et al. 2002; Desapriya, Chipman et al. 2005; Simms and O'Neill 2005). Contrary to popular belief, pedestrians are often vaulted over a striking LTV, rather than run over (Crandall et al. 2002; Simms and O'Neill 2005). This means that the bumper and the upper surface of the front of the LTVs are the direct cause of injury to the legs and head of the pedestrian (Desapriya and Pike 2005; Roudsari et al. 2004; Rowe et al. 2004). Because LTV bonnets are higher than those of cars, there is more severe initial impact on the upper leg and pelvis and a doubling of injuries to vulnerable regions such as the head, thorax, and abdomen (Ashton et al. 1978; Paulozzi 2005; Pinkney et al. 2006; Roudsari et al. 2004; Rowe et al. 2004).

Studies suggest that the expanded number of LTVs in the vehicle fleet represents an increased risk to vulnerable road users. The chief determinants for the severity of injuries in motor vehicle collisions are vehicle size and weight (Crandall et al. 2002; Desapriya, Chipman 2005; Roudsari et al. 2004; Rowe et al. 2004; Simms and O'Neill 2005). A recent U.S. study reported that the increased number of SUVs and pickup trucks on the roads was associated with more pedestrian deaths and higher injury severity (Ballesteros et al. 2004). A study done in the United Arab Emirates found that pedestrians were two times more likely to die in a collision with an LTV than in a collision with a passenger car (Bener et al. 2006). It has been estimated that the changing composition of the car fleet increased the number of road fatalities by 1 percent between 2001 and 2002 in the UK (Broughton 2005). This percentage increase represents approximately 40 additional deaths (Broughton 2005). LTVs are also more likely than cars to be involved in back-over crashes involving child pedestrians. The National Highway Traffic Safety Administration (NHTSA) estimates that more than 7000 injuries and 200 deaths, more than 60 percent of which are suffered by children under 5 or adults over 70, occur every year as a result of back over crashes (Insurance Institute for Highway Safety 2008).

A recent *British Medical Journal* article has shown that the increased threat to vulnerable road users posed by LTVs is likely to reverse some of the hard earned improvements in road safety that have been made over the past decades (Simms and O'Neill 2005).

Systematic reviews of observational studies are rather rare and the relevant experience is limited (Dickersin 2002; Stroup et al. 2000). Most of the work in this area relates to questions for which randomized controlled trials (RCTs) are difficult, impossible, or unethical to conduct (e.g., testing pedestrian fatal injury differences according to vehicle type) However, in many situations randomized controlled designs are not feasible, and only data from observational studies are available (Berlin 1995). Experimental tests with cadavers and dummies can answer many questions regarding pedestrian collisions. However, due to the dynamic nature of the crash, many important biomechanical aspects, such as vehicle-pedestrian interaction, cannot be evaluated in such experimental studies. In order to better understand how pedestrian injuries are influened by changes in vehicle design, in depth studies of real world crashes are necessary (Mock et al. 2000). All available dummy and cadaver studies further demonstrate that LTV inflict more serious injuries and fatalities to pedestrians as compared to cars (Ishikawa et al. 1993; Kerrigan et al. 2005; Mizuno and Kajzer 1999; Okamoto et al. 2003; Wood and Simms 2002; Yao et al. 2007).There is great need for more comprehensive data from real-world crashes. Retrospective cohort studies conducted in this area demonstrate the increased risk of severe pedestrian injury and fatality in collisions with LTVs compared to collisions with passenger cars (Ballesteros et al. 2004; Lefler and Gabler 2004; Simms and O'Neill 2005).

This meta-analysis represents an attempt by the researchers to identify all relevant literature and to recognize and highlight any differences in pedestrian injury outcomes in collisions with LTVs compared to collisions with conventional passenger cars. There are a limited number of individual studies that show the impact of LTVs on pedestrian crashes; however, there are no systematic reviews to demonstrate the impact of LTVs on pedestrian crash outcomes. Because systematic reviews are comprehensive, they represent a far more reliable basis for the decision-making process. We believe that this systematic review can help identify the risk posed by LTVs on vulnerable road users. It will enable policy makers in the automotive industry and government to make necessary design changes to LTVs to minimize fatal injuries to vulnerable road users.

METHODS

Due to the inclusion of observational studies in our review, strict protocols for the meta-analysis of observational studies were followed (Stroup et al. 2000).There was a thorough protocol. Our study protocol was developed in order to synthesize evidence for a well-defined question by using comprehensive and explicit search techniques, specific inclusion criteria for study selection, and methodological quality assessment, followed by systematic review and meta-analysis. We followed Cochrane Collaboration protocols to guide us in this meta-analysis and systematic review (Subzwari et al. 2009). A thorough study quality evaluation was performed using one of the best quality assessment tools available to researchers. There were 878 titles identified by our search; 17 (1.9%) studies survived the selection process, but only 12 (1.3%) were of a satisfactory quality. The *Effective Public Health Project Quality Assessment Tool* was used to assess study quality by applying criteria to assign overall component ratings as strong, moderate, or weak (Effective Public Health Practice Project 2003).Two reviewers, blinded to the study findings, independently assessed study quality, and inter-reviewer reliability was measured (kappa = 83%).

Study Identification

We conducted a search for the studies in bibliographic databases including ATI (Australian Transport Index); Cochrane Injuries Group Specialized Register; EMBASE; ERIC; MEDLINE; National Research Register; PsycINFO; Road Res (ARRB); SIGLE; Science (and Social Science) Citation Index; TRANSPORT (NTIS, TRIS, TRANSDOC, IRRD).

Grey literature and unpublished studies. Web sites of traffic and road accident research bodies, government agencies, and injury prevention organizations were searched for grey literature. Reference lists from selected papers or topic reviews were scanned for potentially relevant papers.

Screening process. Our initial search identified 878 potentially eligible studies. Upon completion of the database searches, titles and abstracts of all references were screened for relevance to the scope of the study. A team of three reviewers (SS, AB, ED) independently evaluated titles and, when available, abstracts to determine whether the articles might meet eligibility criteria. If any reviewer concluded that there was a possibility that the article would fulfill eligibility criteria, we obtained and evaluated the full-text publication.

Eligibility criteria. Our inclusion criteria indicated that RCTs could be included as a potential study design, but we were unable to find any RCTs that met our inclusion criteria. There are no RCTs assessing LTV-related injury and fatality outcomes in the literature. Due to the lack of RCT evidence, we assessed the evidence of the risk of LTV in pedestrian impact crashes using data that were available from observational studies. There are several reasons why there may be a lack of RCTs in this area. Obviously, one reason is that it is unethical to ask pedestrians to intentionally collide with LTVs and cars. Though there are inherent difficulties in assessing the risk of LTV pedestrian crashes, we have used an appropriate study design to demonstrate the potential injury and fatality risks of pedestrian–LTV collisions. We included published and unpublished prospective or retrospective observational studies using real-world pedestrian crash data to compare injury rates among LTV- versus car-associated crashes. Further studies based on real-world crash data with injury as a primary outcome and fatal injuries as a secondary outcome were selected for our review. We excluded computer simulation and other available studies derived from dummy and cadaver studies because interpretability of these studies is limited by their inability to account for the dynamic nature of pedestrian crashes.

Assessment of study eligibility. Our research assistant (AB) blacked out the results in tables and text of all studies identified for full evaluation in the screening process. Two reviewers (SS, ED) independently assessed all studies identified for full evaluation and resolved disagreements by discussion.

Methodological quality assessment. The *Effective Public Health Project Quality Assessment Tool* was used to assess study quality by applying criteria to assign overall component ratings as strong, moderate, or weak (Effective Public Health Practice Project 2003).Two reviewers, blinded to the study findings, independently assessed study quality, and inter-reviewer reliability was measured (kappa = 83%).

Data Extraction

Data were extracted using a predesigned data abstraction form. Two $\times$ 2 tables were created for studies that reported vision changes and differences in the number of injuries between cases and controls. Thus, a full 2 $\times$ 2 table was completed. This process was performed independently by two reviewers (ED and SS) to ensure validity and reproducibility of methods. The abstractors were blinded from the article summary, introduction, and conclusion. Only the methods section of the studies was photocopied and provided to the abstractors to ensure unbiased ratings.

Data analysis. Data analysis was performed using RevMan version 5 software (http://www.ims.cochrane.org/revman). The 2 $\times$ 2 tables were combined using the Mantel Haenszel pooling method. For continuous data, standard mean differences and standard deviations were used. We also pooled odds ratios (OR) by calculating their standard errors and used a generic inverse variance method to pool the results. Funnel plots are a visual tool for investigating publication and other bias in meta-analysis. In this review we have used funnel plots to examine the publication bias.

The reviewers ensured objectivity of data abstraction by using a standardized data abstraction form. Two reviewers (SS, ED) independently extracted data for each eligible study, which included the number and description of participants, type of intervention, duration of follow-up, method of allocation concealment, and outcomes evaluated. Discrepancies were resolved at a meeting of the reviewers. The meta-analysis was performed using Review Manager Software version 5 (http://www.ims.cochrane.org/revman). We combined odds ratios after calculating their standard errors and weighting them according to the inverse of their variances.

RESULTS

Our initial search identified 878 potentially eligible studies, of which 432 were judged appropriate for full-text review. After thorough review of 432 full-text articles by two reviewers (ED, SS) a total of 17 studies were selected for further screening. After thorough review of 17 full-text articles by three of the reviewers (ED, SS, AB), a total of 12 studies were included in the systematic review, 11 of which were included in the meta-analysis (Table I). Data from one study were not available for extraction and inclusion in the meta-analysis.

Twelve studies met our inclusion criteria; 10 were retrospective and 2 were cross-sectional studies.

The overall pooled odds ratio for the risk of injury in pedestrian collisions with LTVs compared to with conventional cars was 1.54 (95%, CI 1.15–1.93, $p = 0.001$) (Table II). Thus, the risk for pedestrians of sustaining fatal injury is 50 percent greater in collisions with LTVs than in collisions with conventional cars.

We assessed for publication bias by producing funnel plots. The symmetry of the plot distribution suggests absence of publication bias. This suggests that our search strategy was comprehensive, and that we located most of the includable studies.

DISCUSSION

Compared to those hit by conventional passenger cars, pedestrians hit by LTVs were more likely to suffer injuries (OR 1.54; 95% CI 1.15–1.93). More than 10 million crashes involving passenger cars and light trucks occurred in the United States in 2005 (McMullin et al. 2009). As this meta-analysis along with the previous literature has shown, certain characteristics of vehicle design can have a marked impact on the injury and fatality outcomes of pedestrians struck by motor vehicles (Crandall et al. 2002; Desapriya and Pike 2005; Matsui 2006; Peden et al. 2004; Sekine at al. 2008; Simms and O'Neill 2005). In addition, light trucks possess several unique features such as relatively poor braking and maneuverability, making them difficult to handle and more dangerous to pedestrians and other vulnerable road users (Anderson 2008).

This issue is especially critical in rapidly motorizing countries. Such countries generally lack the resources to physically separate vulnerable road users from car traffic (Desapriya et al. 2007). Many of these countries have no sidewalks or bicycle paths, and where such amenities do exist they are often heavily obstructed by trees, trash, drainage ditches, and vendors selling goods. Unfortunately, pedestrians, cyclists, rickshaw operators, and moped users still represent the majority of road users in such

Table I Characteristics of studies included in the meta-analysis and systematic review

Study	Duration of follow-up in number of years	Inclusion criteria
DiMaggio et al. (2006) (United States)	—	Children pedestrian aged 5–19 years
Pinkney et al. (2006) (United States)	5	Injury involving child younger than 10 years old injured by a vehicle traveling in a reverse direction in a driveway
Paulozzi (2005) (United States)	1	Pedestrians including wheelchairs, skateboarders, roller-bladers, or cherry pickers
Ivarsson et al. (2005) (United States)	4	Pedestrian involved with a forward-moving late model year vehicle. First impact must be forward of the top of the A-pillar
Lefler and Gabler (2004) (United States)	9	Crash involving pedestrian fatal injuries
Margaritis et al. (2004) (The Netherlands)	1	Passenger car and LTV occupants and pedestrians involved in crashes
Roudsari et al. (2004) (United States)	4	Pedestrian hit by vehicle moving forward, pedestrian should not have been lying or sitting at the time of crash, only passenger cars and LTVs made after 1990, and the striking portion of the vehicle should have been forward of the A pillar and without previous damage
Henary et al. (2003) (United States)	4	Pedestrian involved with a forward-moving late model year vehicle. First impact must be forward of the top of the A-pillar. Age from 2 to 14 years and 19 to 50 years
Ballesteros et al. (2004) (United States)	4	Pedestrians struck either by LTV or a car and treated at Maryland trauma center
Nadler et al. (2001) (United States)	12	Children sustaining motor vehicle injuries in or around the driveway
Holland et al. (2000) (Australia)	4.33	Children younger than 16 years in back-over injuries
Lane et al. (1994) (Canada)	8	Pedestrian involved in crashes with passenger cars and LTVs sustaining fatal or other injuries

Table II Overall pooled odds ratio of the meta-analysis for the risk of fatal injury in pedestrian collision with LTV compared to conventional cars

Study	Odds ratio (SE)	Weight %	Odds ratio (fixed) 95% CI
Lane et al. (1994)	1.9200 (0.6523)	9.44	1.92 (0.64–3.20)
Holland et al. (2000)	2.5000 (0.9163)	4.78	2.50 (0.70–4.30)
Nadler et al. (2001)	0.7000 (0.3567)	31.57	0.70 (0.00–1.40)
Ballesteros et al. (2004)	1.7200 (0.5423)	13.66	1.72 (0.66–2.78)
Henary et al. (2003)	3.3400 (1.2200)	2.70	3.34 (0.95–5.73)
Roudsari et al. (2004)	3.4000 (1.2238)	2.68	3.40 (1.00–5.80)
Margaritis et al. (2004)	0.5600 (0.5798)	11.95	0.56 (0.58–1.70)
Lefler and Gabler (2004)	3.2500 (1.1700)	2.93	3.25 (0.96–5.54)
Paulozzi (2005) DiMaggio et al. (2006)	1.9300 (0.6570)	9.31	1.93 (0.64–3.22)
Pinkney et al. (2006)	2.3000 (0.8329)	5.79	2.30 (0.67–3.93)
Total (95%CI)	2.4100 (0.8796)	5.19	2.41 (0.69–4.13)
		100.00	1.54 (1.15–1.93)

Test for heterogeneity $\chi^2 = 18.74$, df $= 10$ ($P = 0.04$), $I^2 = 46.6$ percent.
Test for overall effect $Z = 7.68$ ($P < 0.00001$).

countries (Desapriya et al. 2007). Consideration of the needs of these vulnerable road users is essential to the safe motorization of developing countries, especially with the increasing proportion of LTVs in the vehicle fleet.

Beyond road and sidewalk engineering, there are other ways to reduce the threat to pedestrians posed by LTVs. The European Commission (EC) has stated that an estimated 50 percent of all fatal and disabling injuries involving motor vehicles could be avoided if all vehicles were designed to be equal in standard to the safest model currently available in each class (Peden et al. 2004). Though mass is an important issue with respect to survivability in crashes, researchers are finding that good vehicle geometry and inclusion of energy-absorbing interfaces could lead to the development of heavy vehicles that are crash comparable with the average mass car fleet (Acierno et al. 2004). The development of pedestrian impact test procedures by the European Experimental Vehicle Committee (EEVC) and the International Standards Organization (ISO) have allowed for the identification of the aspects of vehicle design that are related to injuries sustained by pedestrians (McLean 1996). LTVs differ from cars in three key areas: they have greater mass and increased stiffness, and the bumper is much higher off the ground. These factors change the mechanics of a pedestrian-involved collision (Desapriya and Pike 2005; Crandall et al. 2002; Simms and O'Neill 2005). Contrary to popular belief, pedestrians are often vaulted over a striking LTV, rather than run over. This means that the bumper and the upper surface of the front of the LTVs are the direct cause of injury to the legs and head of the pedestrian (Crandall et al. 2002; Desapriya and Pike 2005; Mock et al. 2002). Because LTV bonnets are higher than those of cars there is a more severe initial impact on the upper leg and pelvis and a doubling of injuries to vulnerable body regions such as the head, thorax, and abdomen (Ashton et al. 1978; Paulozzi 2005; Pinkney et al. 2006; Roudsari et al. 2004). Dummy and cadaver studies reiterated that LTVs more also rigid, absorbing less force during a crash and transferring more energy to what they have hit. Analysis of real-world crash data from the United Staets by Lefler and Gabler (2004) showed that 11.5 percent of pedestrians struck by LTV are fatally injured compared with only 4.5 percent of pedestrians struck by passenger cars. Many studies in North America and Europe have identified that the front, side, and rear design of LTVs can be modified to significantly reduce the harm potential of heavy vehicle crashes and that safety standards for front-end construction could make the vehicles less hazardous to pedestrians and cyclists (Acierno et al. 2004; Crandall et al. 2002; Desapriya and Pike 2005; Simms and O'Neill 2005). Additionally, vehicle shape and energy-absorbing properties of the bumper and the upper surface of the front of the LTVs could be redesigned to reduce the severity of LTV–pedestrian crashes (Crandall et al. 2002; Feist et al. 2008; Hobbs 2001; Matsui 2004, 2005; Roudsari et al. 2004).

The European Commission is investing more resources in developing cars that have increased energy-absorption properties and changing the shape of the front end to enhance safety. The overall objective is to improve the protection of vulnerable road users (Feist et al. 2008).

Unfortunately, the automobile industry is resistant to adopting design changes that could affect consumer selling points such as style and speed, and until recently, political obstacles have made it difficult to pass legislation requiring improved standard safety features (Pless 2004). Recent research has reiterated that LTVs play a considerable role in the phenomenon of back-over collisions (Agran et al. 1994; NHTSA 2006).

There is evidence of progress. In February 2008, the U.S. government enacted the Cameron Gulbrasen Kids Transportation Safety Act. This legislation requires the U.S. Department of Transportation to force automakers to implement new safety standards aimed at preventing three vehicle-related causes of child death and injury: back-overs due to large blind spots such as those that many LTVs possess, collisions caused by children being able to put the car in gear, and strangulation by power windows (Senator John Sununu honored for work in helping to enact Cameron Gulbrasen Kids Transportation Safety Act, February 14, 2008; http://nhpolitics.com/). This act of governance is an important step in improving child and other pedestrians' safety. Hopefully, other countries will soon start working toward implementation of similar measures. Policy makers in collaboration with the public health community need to work with the vehicle industry to encourage development of safer vehicle front ends in LTVs. *Consumer Reports* (2008) showed that LTVs have an average blind spot of 14 feet, compared to 5 feet for a smaller mid-sized sedan. Vehicle manufacturers are also should be encouraged to invest in vehicle back-over avoidance technology. Meaningful investment in vehicle back-over avoidance technology is necessary to detect children behind vehicles of a large size such as LTVs (NHTSA 2006). The NHTSA's (2006) research on nine vehicles equipped with currently available technology such as cameras and electronic sensor-based systems found that the detection of objects was not consistent, and children were not well detected (Mazzae 2007).

Strengths and Limitation of Our Review

One of the main strengths of our review was the comprehensive search strategy including multiple electronic databases. Our search strategy yielded a large number of records (close to 2000). This is partly due to the fact that searching according to study type is possible only for controlled trials. Initial screening by titles and abstracts to select relevant studies reduced the number of potentially relevant reports to a reasonably manageable level. However, it was not always straightforward to judge relevance from abstracts and this has been a tedious and time-consuming process. We face the same difficulty and important challenged for systematic reviews. We could not identify LTV–pedestrian crash literature from less-developed countries. Even though rapidly developing countries face more problems related to rapid motorization in their respective countries, there is still a lack of research done in these countries to understand vehicle crash-related problems due to resource constraints and conflict of priorities. Accordingly, we have found no candidate studies from developing countries that met our inclusion criteria. Studies from these countries are likely to be published in non-indexed and non-English journals. There is much less research conducted in those countries, considering the difficulties surrounding securing funds for research. Our systematic review was based largely on studies derived from the United States. We suggest that our current analysis has significant advantages because it is based on several large databases, including the National Highway Traffic Safety Administration (Fatality Analysis Reporting System, General Estimates System, PCD-CIREN and NASS) and health care–related patient and insurance industry databases. The Crashworthiness Data System (CDS) is a national probability sample of light passenger vehicles (passenger cars). As such, the sample populations within this study maintain the diversity to be representative of the population as a whole. Importantly, the NHTSA-CIREN and NASS databases that were used among studies function as a coordinated network, with uniform methods for case enrollment, crash investigation, medical and injury data collection and analysis of injury sources, and biomechanical causation. In addition, our review includes studies from Australia, Canada, and The Netherlands.

Implications for Future Research and Policy

Our findings document a major risk associated with LTVs. This systematic review provides new evidence that LTVs are a risk factor for pedestrian fatal injuries. Our findings have important implications for future vehicle design modification. The traffic safety research community must respond. There are still important questions to be answered concerning the LTVs and risk of fatal injury in traffic crashes. This may require an internationally funded, well-designed study that should be conducted within a clear, well-supported international collaborative framework. There is an urgent need to conduct comprehensive research on LTV and pedestrian crashes utilizing data from developing countries, where there is no sufficient and effective road infrastructure to separate pedestrians and vehicles.

The increased risk of severe injury and fatality in collisions with LTVs is also evident in the pediatric population. A recent study shows that LTVs were four times as likely to be associated with fatal injury in 5- to 9-year-old pedestrians compared with passenger cars (OR 4.2; 95% CI 1.9–9.5; DiMaggio et al. 2006). However, available literature and crash investigation has not sufficiently evaluated the mechanisms of child pedestrian collisions outside driveway crashes. In order to answer the critical questions regarding the differences in children injury profile among passenger vehicle and LTVs, further studies with larger sample sizes are required.

There is increasing interest in the health-promoting potential of physical activity including walking in our communities around the globe. A systematic review of strategies that promote physical activity (Sonkin et al. 2006) concluded that walking is the most important form of physical activity that should be encouraged to improve public health given that it is the activity most widely available. Vehicle danger is a disincentive to active transport and reducing the traffic fatal injury risks for child pedestrians and cyclists must be an important part of any strategy to encourage walking and cycling to reduce childhood obesity and active lifestyles in our communities. In particular, research in the United States (Centers for Disease Control 2005) and in the UK shows that traffic danger is an inhibitor for children to walk to school and cycle (Rowland et al. 2003). This fear results in parents discouragingtheir children from walking and cycling to school. An additional study, also in the UK, found that children of parents who were quite worried or very worried about traffic danger were 1.6 times more likely to be driven to and from school (odds ratio 1.6, 95% confidence interval 1.0–2.5; DiGuiseppi et al. 1995).

In the report and other follow-up memoranda, the British Medical Association (BMA) identified traffic danger as an inhibitor of walking and cycling and suggested strategies that make roads safer for vulnerable road users (BMA 2003). In accordance with the BMA, the World Health Organization (WHO) also identified fear of traffic danger as an inhibitor of pedestrian activity, especially in older individuals (WHO 2002). In 2009, a Committee on Injury, Violence, and Poison Prevention, American Academy of Pediatrics policy statement urged legislation that allows communities to create programs and environmental improvements to neighborhoods that can support children's safer commuting to school.

The problem is not limited to Western nations; researchers in India report that children are being discouraged from walking or bicycling to school because of fears of road traffic and crime (Bhave et al. 2004).Therefore, it is paramount that vehicle manufacturers apply significant changes to vehicle front designs as early as possible (Pucher and Dijkstra 2003). It is necessary that public health policy makers focus their attention on promoting safer vehicle fronts, incorporating the evidence-based strategies to reduce pedestrian injuries and fatalities. In the coming years, in part because of the current economic recession and the concern over dwindling oil supplies and environmentalism, the automotive industry will need to make significant changes. As it faces pressures to redefine vehicle manufacturing, there is good opportunity for public health to influence the industry to incorporate into their production processes effective technology that could reduce risk of injuries to vulnerable pedestrians (Desapriya et al. 2009).

A recent European study utilizing numerical simulations and experimental testing, including a full-scale test with a pedestrian dummy, shows that an energy-absorbing front end (and changing the shape of the front end) and side of LTVs and other heavy vehicles can reduce up to 90 percent of injuries to the head and lower extremities at impact velocities of up to 40 km/h (Feist et al. 2008).

We believe that vulnerable road users could be better protected from the impact of LTVs if they were fitted with external airbags and energy-absorbing bodywork. An energy-absorbing bumper system made of a foam-type resin of polypropylene, polyurethane, or a similar product is one such concept (Evans and Morgan 1999).

To date, bumper systems of LTVs are basically designed to prevent or limit physical damage to expensive components of the vehicle and thereby reduce insurance costs of replacing parts of the vehicles in crashes by merely protecting the hood, trunk, grill, fuel, exhaust, and cooling system in low-velocity crashes. Now it is time to think equally on insurance cost reduction in crashes and incorporate effective technology and materials that could reduce the impact of LTV crashes on vulnerable road users.

Road users everywhere deserve better and safer road travel (Bener et al. 2006; Desapriya et al. 2006; Matsui 2005; Mohan 2002; Peden et al. 2004). With the ever increasing rates of obesity around the world, the rights of pedestrians to use roadways safely, both as a means of transport and as a leisure activity, need to be safeguarded. LTVs pose a risk to pedestrians, but modifications in their front design, energy-absorbing properties of the bumper and the upper surface of the front of the LTVs, and in road engineering (traffic calming) could improve the safety of all road users.

ACKNOWLEDGMENTS

The British Columbia Ministry of Healthy Living and Sports has provided funding toward this project. We appreciate Dian Leung and Giulia Scime, our research assistants, and their assistance with the revision of this manuscript.

We acknowledge the outstanding work of selecting candidate studies for this systematic review and meta-analysis by Dr. Sayed Subzwari (lead author of recent Cochrane Systematic Review on vision screening and older driver traffic crashes and systematic review meta analysis of cataract surgery and older driver traffic crashes, published recently in *Injury Prevention*) Dr. Ediriweera Desapriya (coauthor of the same recent Cochrane Systematic Review), and Ana Maria Basic, who blinded articles for us.

REFERENCES

Acierno S, Kaufman R, Rivara FP. (2004) Vehicle Mismatch: Injury Patterns and Severity. *Accid. Anal. Prev.*, Vol. 36, pp.761–772.

Agran PF, Winn DG, Anderson CL. (1994) Differences in Child Pedestrian Injury Events by Location. *Pediatrics*, Vol. 93, pp. 284–288.

Anderson M. (2008) Safety for Whom? The Effects of Light Trucks on Traffic Fatalities. *J. Health Econ.*, Vol. 27, pp. 973–989.

Ashton SJ, Pedder JB, Mackay GM. (1978) Influence of Vehicle Design on Pedestrian Leg Injuries. Proc. *22nd Annual Conference of the American Association for Automotive Medicine*, pp. 216–236.

Ballesteros MF, Dischinger PC, Langenberg P. (2004) Pedestrian Injuries and Vehicle Type in Maryland, 1995–1999. *Accid. Anal. Prev.*, Vol. 36, pp. 73–81.

Bener A, Ghaffar A, Azab A, Kutty MS, Toth F, Lovasz G. (2006) The Impact of Four-Wheel Drives on Traffic Disability and Deaths Compared to Passenger Cars. *J. Coll. Phys. Surg. Pakistan*, Vol. 16, pp. 257–260.

Berlin JA. (1995) Invited Commentary. *Am. J. Epidemiol.*, Vol. 142, pp. 383–387.

Bhave S, Bavdekar A, Otiv M. (2004). IAP National Task Force for Childhood Prevention of Adult Diseases: Childhood Obesity. *Indian Pediatr.*, Vol. 41, pp. 559–575.

British Medical Association. (2003) *Children's Environment and Health Action Plan for Europe*. British Medical Association, London.

Broughton J. (2005) *Car Occupant and Motor-cyclist Deaths, 1994–2002*. Transport Research Laboratory, Crowthorne, England. TRL Report 629.

Centers for Disease Control. (2005) Barriers to Children Walking to or from School—United States, 2004. *Morb. Mortal. Wkly. Rep.*, Vol. 54, pp. 949–952.

Committee on Injury, Violence, and Poison Prevention, American Academy of Pediatrics. (2009) Policy Statement-Pedestrian safety. *Pediatrics*, Vol. 124, pp. 802–812.

Consumer Reports. (2008) *The Problem of Blind Spots: The Area Behind Your Vehicle Can Be a Killing Zone*. Available at: http://www.consumerreports.org/cro/cars/car safety/car-safetyreviews/mind-that-blind-spot-1005/overview/ (accessed August 13, 2009).

Crandall JR, Bhalla KS, Madeley NJ. (2002) Designing Road Vehicles for Pedestrian Protection. *Br. Med. J.*, Vol. 324, pp. 1145–1148.

Dandona R. (2005) *SUV's and Road Safety in Developing Countries—BMJ Rapid Response*. Available at: http://www.bmj.com/cgi/eletters/331/7520/787#118814 (accessed on August 12, 2007).

Desapriya EB, Chipman M, Joshi P, Pike I. (2005) The Risk of Injury and Vehicle Damage in Vehicle Mismatched Crashes. *Int. J. Inj. Contr. Saf. Promot.*, Vol. 12, pp. 191–192.

Desapriya EB, Pike I. (2005) Sports Utility Vehicles and Older Pedestrians—Achieving Compatibility in Motor Vehicle Crashes. *Br. Med. J.*, Vol. 331, pp. 966–967.

Desapriya E, Pike I, Joshi P. (2006) Risks on the Roads. *Can. Med. Assoc. J.*, Vol. 1, p. 1743.

Desapriya EB, Pike I, Kinney J. (2005) The Risk of Injury and Vehicle Damage Severity in Vehicle Mismatched Side Impact Crashes in British Columbia Canada. *Int. Assoc. Traffic Saf. Sci. Res.*, Vol. 29, pp. 60–66.

Desapriya, EB, Pike I, Raina P. (2006) Severity of Alcohol-Related Motor Vehicle Crashes in British Columbia: Case-Control Study. *Int. J. Inj. Contr. Saf. Promot.*, Vol. 13, pp. 89–94.

Desapriya E, Pike I, Turcotte K. (2007) Sports Utility Vehicles and Vulnerable Road Users. *Am. J. Publ. Health*, Vol. 97(Suppl. 1), pp. S4–S5.

Desapriya E, Turcotte K, Subzwari S, Pike I. (2009) Smoking Inside Vehicles Should Be Banned Globally. *Am. J. Publ. Health*, Vol. 99, pp. 1158–1159.

Dickersin K. (2002) Systematic Reviews in Epidemiology: Why Are We So Far Behind? *Int. J. Epidemiol.*, Vol. 31, pp. 6–12.

DiGuiseppi C, Roberts I, Li L, Allen D. (1995) Determinants of Car Travel on Daily Journeys to and from School. *Br. Med. J.*, Vol. 316, pp. 1426–1428.

DiMaggio C, Durkin M, Richardson LD. (2006) The Association of Light Trucks and Vans with Paediatric Pedestrian Deaths. *Int. J. Inj. Contr. Saf. Promot*., Vol. 13, pp. 95–99.

Effective Public Health Practice Project. (2003). *Effective Public Health Project Quality Assessment Tool*. Available at: https://www.myhamilton.ca/NR/rdonlyres/04A24EBE-2C46-411D-AEBA-95 A60FDEF5CA/0/QualityTool2003.pdf (accessed August 10, 2007).

Evans D, Morgan T. (1999) *Engineering Thermoplastic Energy Absorbers for Bumpers*. SAE Paper 1999-01-1011. http://www.sae.org/technical/papers/1999-01-1011

Feist F, Gugler J, Giorda A, Avalle M, Puppini R. (2008) Improvements to the Protection of Vulnerable Road Users: Retrofittable, Energy-absorbing front End for Heavy Goods Vehicles. *J. Crashworthiness*, Vol. 13, pp. 609–627.

Henary BY, Crandall J, Bhalla K, Mock CN, Roudsari BS. (2003) Child and Adult Pedestrian Impact: The Influence of Vehicle Type on Injury Severity. *Annu. Proc. Assoc. Adv. Automot. Med.*, Vol. 47, pp. 105–126.

Hobbs A. (2001) *Safer Car Fronts for Pedestrians and Cyclists*. European Transport Safety Council, Brussels, Belgium.

Holland AJ, Liang RW, Singh SJ, Schell DN, Ross FI, Cass DT. (2000) Driveway Motor Vehicle Injuries in Children. *Med. J. Aust.*, Vol. 21, pp. 192–195.

Insurance Institute for Highway Safety. (2008) *Status Rep.*, 43(5).

Ishikawa H, Kajzer J, Schroeder G. (1993) Computer Simulation of the Impact Response of the Human Body in Car Pedestrian Accidents. Proc. *37th Stapp Car Crash Conference*, pp. 235–248.

Ivarsson BJ, Crandall JR, Okamoto M. (2006) Influence of Age-Related Stature on the Frequency of Body Region Injury and Overall Injury Severity in Child Pedestrian Casualties. *Traffic Inj. Prev*., Vol. 7, pp. 290–298.

Kerrigan J, Kam C, Murphy D, Bose D, Ivarsson J, Crandall J. (2005) Kinematic Comparison of the Polar II and PMHS in Pedestrian Impacts with a Sport Utility Vehicle. Proc. *IRCOBI Conference*, pp. 159–174.

Krug E. (1999) Injury: A Leading Cause of Global Burden of Disease. Geneva: WHO.

Krug EG, Sharma GK, Lozano R. (2000) The Global Burden Injuries. *Am. J. Publ. Health*, Vol. 90, pp. 523–526.

Lane PL, McClafferty KJ, Nowak ES. (1994) Pedestrians in Real World Collisions. *J Trauma*, Vol. 36, pp. 231–236.

Lefler DE, Gabler HC. (2004) The Fatality and Injury Risk of Light Truck Impacts with Pedestrians in the United States. *Accid. Anal. Prev*., Vol. 36, pp. 295–304.

Lieber R, Bernard TS. (2008) Ditch the Gas Guzzler? Well, Maybe Not Yet. New York Times- http://www.nytimes.com/2008/08/02/business/yourmoney/02money.html

Margaritis D, Hoogvelt B, Vries, Y, Klootwijk C, Mooi H. (2004) An Analysis of Sport Utility Vehicles Involved in Road Accidents.TNO Automotive, The Netherlands, Paper Number 05-0370. http://www-nrd.nhtsa.dot.gov/pdf/esv/esv19/05-0370-O.pdf

Matsui Y. (2004) Evaluation of Pedestrian Subsystem Test Method Using Legform and Upper Legform Impactors for Assessment of High-Bumper Vehicle Aggressiveness. *Traffic Inj. Prev.*, Vol. 5, pp. 76–86.

Matsui Y. (2005) Effects of Vehicle Bumper Height and Impact Velocity on Type of Lower Extremity Injury in Vehicle-Pedestrian Accidents. *Accid. Anal. Prev*., Vol. 37, pp. 633–640.

Mazzae, E. (2007) NHSTA's Backover Crash Prevention Research. Available at: http://www.nhtsa.dot.gov/staticfiles/DOT/NHTSA/NRD/Multimedia/PDFs/Public%20Paper/SAE/2007/2007%20SAE%20Gov%20Ind%20Mtg_Mazzae.pdf (accessed August 18, 2009).

McLean AJ. (1996) *Pedestrian Friendly Vehicle Front Structures: A Review of the Literature*. Australian Government Publishing Service, Canberra, Australia.

McMullin BT, Rhee JS, Pintar FA, Szabo A, Yoganandan N. (2009) Facial Fractures in Motor Vehicle Collisions: Epidemiological Trends and Risk Factors. *Arch. Facial Plast. Surg*., Vol. 11, pp. 165–170.

Mock C, MacKenzie E, Jurkovich G, Burgess A, Cushing B, deLateur B, McAndrew M. (2000) Determinants of Disability after Lower Extremity Fracture. *J Trauma.*, Vol. 49, pp. 1002–1011.

Mock CN, Grossman DC, Kaufman RP, Mack CD, Rivara FP. (2002) The Relationship between Body Weight and Risk of Death and Serious Injury in Motor Vehicle Crashes. *Accid Anal Prev.*, Vol. 34, pp. 221–228.

Mohan D. (2002) Road Safety in Less-Motorized Environments: Future Concerns. *Int. J. Epidemiol*., Vol. 31, pp. 527–32.

Mizuno K, Kajzer J. (1999) Compatibility Problems in Frontal, Side, Single Car Collisions and Car-to-Pedestrian Accidents in Japan. *Accid. Anal. Prev*., Vol. 31, pp. 381–389.

Murray CJ, Lopez AD. (1997a) Alternative Projections of Mortality and Disability by Cause 1990–2020: Global Burden of Disease Study. *Lancet*, Vol. 349, pp. 1498–1504.

Murray CJ, Lopez AD. (1997b) Global Mortality, Disability, and the Contribution of Risk Factors: Global Burden of Disease Study. *Lancet*, Vol. 17, pp. 1436–1442.

Nadler EP, Courcoulas AP, Gardner MJ, Ford HR. (2001) Driveway Injuries in Children: Risk Factors, Morbidity, and Mortality. *Pediatrics*, Vol. 108, pp. 326–328.

National Highway Traffic Safety Administration, US Department of Transportation. (2006) *Vehicle Backover Avoidance Technology Study—Report to Congress*. Available at: http://www.nhtsa.dot.gov/staticfiles/DOT/NHTSA/Vehicle%20Safety/Studies%20&%20 Reports/Associated%20Files/BackoverAvoidance TechStudy.pdf (accessed August 13, 2008).

Okamoto Y, Sugimoto T, Enomoto K, Kikuchi J. (2003) Pedestrian Head Impact Conditions Depending on the Vehicle Front Shape and Its Construction—Full Model Simulation. *Traffic Inj Prev*., Vol. 4, pp. 74–82.

Paulozzi LJ. (2005) United States Pedestrian Fatality Rates by Vehicle Type. *Inj. Prev*., Vol. 11, pp. 232–236.

Peden M, Scurfield R, Sleet D. (2004) *World Report on Road Traffic Injury Prevention*. World Health Organization, Geneva.

Pinkney KA, Smith A, Mann NC, Mower GD, Davis A, Dean JM. (2006) Risk of Pediatric Back-over Injuries in Residential Driveways by Vehicle Type. *Pediatr. Emerg. Care*, Vol. 22, pp. 402–407.

Pucher J, Dijkstra L. (2003) Promoting Safe Walking and Cycling to Improve Public Health: Lessons from The Netherlands and Germany. *Am. J. Publ. Health*, Vol. 93, pp. 1509–1516.

Roudsari BS, Mock CN, Kaufman R, Grossman D, Henary BY, Crandall J. (2004) Pedestrian Crashes: Higher Injury Severity and Mortality Rate for Light Truck Vehicles Compared with Passenger Vehicles. *Inj. Prev.*, Vol. 10, pp. 154–158.

Rowe SA, Sochor MS, Staples KS, Wahl WL, Wang SC. (2004) Pelvic Ring Fractures: Implications of Vehicle Design, Crash Type, and Occupant Characteristics. *Surgery.*, Vol. 136, pp. 842–847.

Rowland B, DiGuiseppi C, Gross M, Afolabi E, Roberts I. (2003) Randomized Controlled Trial of Site Specific Advice on School Travel Patterns. *Arch. Dis. Child*, Vol. 88, pp. 8–11.

Sekine Y, Takahashi K, Hayamizu H, Kawamoto D, Nakagawa D. (2008) Compatibility between Sports-Utility Vehicles and Sedan-Type Vehicles. *Int. J. Crashworthiness*, Vol. 13, pp. 551–558.

Senator John Sununu Honored for Work in Helping to Enact Cameron Gulbrasen Kids Transportation Safety Act, February 14, 2008. Available at: http://nhpolitics.com/ (accessed August 12, 2008).

Simms C, O'Neill D. (2005) Sports Utility Vehicles and Older Pedestrians. *Br. Med. J.*, Vol. 8, pp. 787–788.

Sonkin B, Edwards P, Roberts I, Green J. (2006) Walking, Cycling and Transport Safety: An Analysis of Child Road Deaths. *J. Roy. Soc. Med.*, Vol. 99, pp. 402–405.

Starnes M, Longthorne A. (2003) *Child Pedestrian Fatality Rates by Striking Vehicle Body Type: A Comparison of Passenger Cars, Sport Utility Vehicles, Pickups, and Vans*. National Highway Traffic Safety Administration. DOT HS 809 640 (Traffic Safety Facts Research Note).

Stroup DF, Berlin JA, Morton SC, Olkin I, Williamson GD, Rennie D, Moher D, Becker BJ, Sipe TA, Thacker SB. (2000) Meta-analysis of Observational Studies in Epidemiology: A Proposal for Reporting. Meta-analysis of Observational Studies in Epidemiology (MOOSE) Group. *J. Am. Med. Assoc.*, Vol. 83, pp. 2008–2012.

Subzwari S, Desapriya E, Babul-Wellar S, Pike I, Turcotte K, Rajabali F, Kinney J. (2009) Vision Screening of Older Drivers for Preventing Road Traffic Injuries and Fatalities. *Cochrane Database of Systematic Reviews*, Vol. 21, No. 1: CD006252.

White M. (2004) The "Arms Race" on American Roads: The Effect of Sport Utility Vehicles and Pickup Trucks on Traffic Safety. *J. Law Econ.*, Vol. 47, pp. 333–355.

Wood DP, Simms CK. (2002) Car Size and Injury Risk: A Model for Injury Risk in Frontal Collisions. *Accid. Anal. Prev.*, Vol. 34, pp. 93–99.

World Health Organization. (2002) *Physical Activity through Transport as Part of Daily Living Changes in the Global Vehicle Fleet and Associated Risks to Vulnerable Road Users*. World Health Organization, Geneva.

Yao J, Yang J, Otte D. (2007) Head Injuries in Child Pedestrian Accidents—In-Depth Case Analysis and Reconstructions. *Traffic Inj. Prev.*, Vol. 8, pp. 94–100.