Effects of vehicle safety design on road traffic deaths, injuries, and public health burden in the Latin American region: a modelling study

Kavi Bhalla, Kevin Gleason

Lancet Glob Health 2020; 8: e819–28

See Comment page e746

Department of Public Health Sciences, University of Chicago, Chicago, IL, USA (K Bhalla PhD, K Gleason BA)

Correspondence to: Dr Kavi Bhalla, Department of Public Health Sciences, University of Chicago, Chicago, IL 60637, USA
kavibhalla@gmail.com

Summary

Background The Sustainable Development Goals (SDGs), which aim to halve global traffic deaths by 2020, will not be met by most low-income and middle-income countries (LMICs). In Latin America and the Caribbean (LAC) region, traffic deaths have remained stable at a high-level despite strong progress in other health domains. We evaluated the effects of road safety interventions in LAC and estimated the benefits that vehicle design improvements would have in this region.

Methods In our study done in October, 2018, we used a counterfactual analysis to assess the reduction in deaths and disability-adjusted life years (DALYs) lost if eight proven vehicle safety technologies were made more widely available in LAC countries. We estimated: (1) country-level incidence of traffic injuries, (2) the effectiveness of technologies through a systematic literature review, (3) the prevalence of car safety technologies, and (4) the lives saved and DALYs averted if all cars had these technologies. We characterised uncertainty in estimates by reporting the sensitivity of the results to alternative modelling assumptions.

Findings Increasing availability of electronic stability control, which includes antilock-brake systems, would have the largest benefits in the LAC region, estimated at 19·4% (sensitivity analysis range 8·6–31·1) fewer deaths and 17·0% (5·7–29·2) fewer DALYs. Increasing use of seatbelts would reduce deaths by 12·1% (9·1–15·5) and DALYs by 12·6% (9·4–16·3). Optimisation for side-impacts would result in 6·3% (3·1–6·5) fewer deaths, and improvements to vehicle front-end design would result in 6·0% (2·2–10·4) fewer deaths. The overall effect of improved vehicle design in the region would be 28·1% (12·8–39·2) fewer deaths, and 29·1% (13·5–39·8) fewer DALYs. Other safety technologies modelled, including airbag (front and side), side door beam, and side structure and padding, have smaller benefits.

Interpretation Regulating and encouraging the use of proven vehicle safety technologies in LMICs would have large gains and needs to be prioritised in the SDG agenda for 2030.

Funding Inter-American Development Bank.

Introduction

As the UN Decade of Action for Road Safety (2011–20) draws to a close, it has become clear that countries have made much less progress in reducing traffic injuries than in other health domains. Although Sustainable Development Goal (SDG) 3.6 aimed to halve the number of global traffic deaths by 2020, deaths have continued to rise, or remained stable at a high level, in most low-income and middle-income countries (LMICs). In 2016, road traffic crashes in the Latin America and the Caribbean (LAC) region killed approximately 110 000 people and were the fifth leading cause of disability-adjusted life years (DALYs) lost in global burden of disease (GBD) rankings.[1] Among people aged between 15 and 49 years, traffic injuries were the second leading cause of death in the LAC region, behind interpersonal violence. Although mortality from traffic injuries has remained stable in the region, there have been remarkable strides in reducing the burden of many diseases. Between 2000 and 2017, DALYs due to lower respiratory infections in the region declined by 45%, diarrhoeal disease declined by 64%, and HIV/AIDS by 39%.[1]

In February, 2020, the 3rd Global Ministerial Conference on Road Safety adopted the Stockholm Declaration, calling on countries to reduce traffic deaths by half by 2030. An understanding of what has worked in high-income countries (HICs) is important in this dialogue. By contrast to LMICs, HICs have done remarkably well at reducing traffic injuries. In the 1960s, traffic death rates in countries in the Organisation for Economic Cooperation and Development (OECD) were similar to those in the LAC region in 2016 (22 deaths per 100 000 people). However, death rates have declined steadily in OECD countries since the 1970s, and are now approximately five deaths per 100 000 people in many countries.[2] This success has been attributed to broad based efforts across a wide range of areas, including the strengthening of institutional

Research in context

Evidence before this study

We searched PubMed and Embase for publications in English, without restriction by date, and that reported evaluations of the effect of vehicle design on the burden of road traffic injuries in LMICs using the search terms “traffic injuries” AND “vehicle design” OR “vehicle safety” AND “low- and middle-income countries” AND “effectiveness”. We found several studies that estimated the effects of various road safety interventions in LMICs but none that assessed the population-level effects of improving vehicle safety technologies, with the exception of studies that assessed the effects of seatbelt use.

Added value of this study

We estimated the effect of increasing the availability of proven vehicle safety technologies on mortality and population health burden of road traffic injuries in countries in the LAC region. We focused on technologies that relate with eight UN regulations that are considered high priority, and which have been available in high-income countries (HICs) long enough to evaluate their effects on traffic injuries. We found that, although the extent of benefits for countries vary on the basis of baseline conditions (especially for prevalence of technologies, crash configurations, and types of road users injured), all countries will see large benefits from increased availability of these technologies. Increasing the availability of electronic stability control would lead to the largest benefits in terms of lives saved and disability averted in the LAC region. A large portion of the health gains derive from antilock-brake systems (ABS), which are integrated in electronic stability control technologies. Motorcycle-ABS, in particular, are one of the few vehicle technologies that can have a large effect on reducing injuries in countries (eg, Colombia) where motorcyclists comprise a large proportion of deaths and injuries. Increasing the use of occupant protection technologies, including seatbelts, frontal and side air bags, side structure, and padding, will have a large effect on traffic deaths in countries (eg, Argentina) where occupants comprise a large proportion of deaths and injuries. Seatbelts are a highly effective technology that are already available in almost all cars in the LAC region, but seatbelt use is low in this region. By making the structures that interact with pedestrians (eg, bumper, hood, windshield, and A-pillar) softer, the front-end design of cars can help to reduce pedestrian injuries substantially, but the benefits would be greater if front-ends of other vehicles, especially buses and trucks, were also improved.

Implications of all the available evidence

Road traffic injuries in most LMICs are either rising or stable at a high-level despite strong global advocacy as part of the UN Decade of Action for Road Safety (2011–20). Many research papers show that improvements in vehicle safety design were a primary driver for the large reductions in traffic death rates in HICs since the 1960s. Nevertheless, vehicle design is not receiving adequate attention in global road safety advocacy efforts. 124 LMICs require only one (or none) of the eight priority regulations recommended by the UN World Forum for Harmonization of Vehicle Regulations. Therefore, our findings emphasise the importance of improving vehicle safety design for achieving the Sustainable Development Goals road safety agenda for 2030. Such improvements can be achieved by a combination of vehicle design regulations and the creation of consumer demand for safer cars through mechanisms like new car assessment programmes (NCAPs).

capacity, improvements in vehicle and roadway design, increased enforcement of road safety regulations, progress in medical care, and road user education.[3,4] Consequently, WHO recommends for LMICs to undertake multisectoral action spanning health, transport, education, and law enforcement, among others.[5]

Although there is no doubt that HICs undertook a wide range of interventions, some factors, such as improvements in vehicle design, had much larger effects than others.[6–8] For instance, the risk of driver death in a 2009 model passenger vehicle sold in the USA is estimated to be half that associated with vehicle models sold in 1984.[6] In fact, a review by the US National Highway Traffic Safety Administration concluded that vehicle design improvements between 1960 and 2012 reduced traffic mortality by as much as all other factors combined.[9]

Despite the potential benefits, vehicle design is neglected in policy efforts in LMICs. Although there have been several studies that have evaluated the effects of road safety interventions in LMICs,[10–12] to our knowledge, none has focused on estimating the benefits from vehicle design improvements in LMICs. Although the UN World Forum for Harmonization of Vehicle Regulations has developed a legal framework and identified eight regulations that should be prioritised, only 40 countries (mainly HICs) have implemented these. Among LMICs, 124 countries require only one (or none) of the eight regulations.[5] Crash testing of the most popular brands of cars sold in LMICs show that most will not pass even the relatively low safety requirements of UN regulations, and thus are substantially less safe than vehicles commonly available in HICs.[13,14] Although there is little systematic evidence on how these processes (regulation and consumer information by new car assessment programmes [NCAPs]) affect vehicle prices, estimates from global NCAPs suggest that the cost of these technologies is fairly low (eg, antilock-brake systems [ABS] plus electronic stability control are priced approximately between ~US $75–100).[15]

Therefore, we aimed to assess the reduction in traffic injuries that could be achieved if proven vehicle safety technologies were widely available in the LAC region. We focused on eight technologies that relate to the priority UN regulations (table 1) and that have been available in HICs long enough for their effects on traffic injuries to be systematically evaluated. These technologies are: ABS, electronic stability control, occupant restraints (ie, safety belts and child seats), frontal airbags, side airbags, side door beams, side structure and padding, and vehicle front-end design for pedestrian protection. In addition, we estimate the effects of overall improvements in side-impact protection and vehicle design. The estimated benefits depend primarily on how well the technologies do in the most common crash configurations. To show these variations, we present results for six countries (Argentina, Brazil, Colombia, Ecuador, Mexico, and Uruguay), in addition to the LAC region as a whole.

Methods

Study design

We did a counterfactual analysis to assess the number of deaths, injuries, and DALYs that would be averted in a scenario in which selected safety technologies were available in the entire fleet of vehicles. In summary, we used the following steps for each intervention: (1) identify which crash configurations are affected by the intervention, (2) estimate relative risks (ie, how much the technologies affect the probability of crashes and injuries) in different crash configurations, which were based on a systematic review of the literature, (3) estimate the proportion of vehicles that have the intervention, (4) and estimate the number of lives saved (and DALYs averted) in the scenario in which all vehicles had the safety technology. The method that we used requires many assumptions, which are summarised in table 2.

Estimation of baseline deaths and injuries

In most LMICs, official statistics on traffic injuries are sourced from traffic police, which can have substantial under-reporting.[17] In the LAC region, however, data for total traffic deaths in most countries are relatively reliable (compared with other LMICs) and within 25% of the estimates based on vital ation data by the GBD study (appendix p 1).[1] Nevertheless, there are large discrepancies between the proportions of road user deaths reported in official statistics and those reported in the GBD study, reflecting the poor quality of coding for types of road user in the vital registration data for the LAC region.[18] Therefore, for baseline estimates of deaths and injuries, we used the 2016 GBD estimates[1] for total road traffic deaths and non-fatal injuries (disaggregated by age and sex) in each country, which we further disaggregated by type of road user using the proportions reported in official statistics presented in the WHO Global Status Report on Road Safety.[5]

To estimate crash configurations (eg, rollover, side or frontal impact), we obtained records from traffic police databases from Argentina, Chile, Colombia, Costa Rica, Ecuador, Guatemala, Honduras, and Uruguay. However, none of the records from these countries could be used for estimating crash configuration of occupant crashes, usually because this information was not collected or had high-levels (ie, >75%) of missing data. Therefore, we applied estimates of crash configurations for occupants based on data from the USA.[19] We estimated impacting vehicles for pedestrians using crash data from six countries: Argentina, Colombia, Costa Rica, Ecuador, Guatemala, and Uruguay (appendix p 4). For other countries, we used the average of estimates from available countries.

Estimation of technology penetration

Our literature review and online searches showed no primary sources on the prevalence of any of the eight safety technologies in the vehicle fleet. Therefore, we estimated this prevalence on the basis of historical data for the availability of technologies in new vehicles collected by AutoData (Montevideo, Uruguay).[20] These data were available for three countries in 2017: Uruguay, Colombia, and Argentina; and for 2000 onwards for ABS, electronic stability control, frontal airbags, and side-airbags in new vehicle sales for Uruguay (appendix p 5). Following previous work on the adoption of technology and vehicle fleet attrition,[21,22] we used a logistic function to model technology adoption (ie, the availability of technologies in new vehicles sold) to the historical data from Uruguay, and applied it to the 2017 data from other countries to estimate the historical availability of these technologies. Finally, we used historical vehicle registration data to estimate the prevalence of the technologies in the on-road vehicle fleet. Information about motorcycle ABS were not

See Online for appendix

	Associated technologies
UN regulation 94 and 95: frontal impact protection and side impact protection; crashworthiness in crash tests at specific speeds	Occupant restraints, airbags (frontal and side), side structure and padding, and side door beams
UN regulation 140: electronic stability control; prevents skidding and loss of control, requires antilock brakes	Electronic stability control
UN regulation 78: motorcycle antilock brakes; helps maintain control during emergency braking	Motorcycle-antilock brakes
UN regulation 127: pedestrian front protection; vehicle front-end modifications to reduce severity of pedestrian injuries	Vehicle front-end design
UN regulation 14, 16, and 129: seatbelt, seatbelt anchorages, and child restraints	Occupant restraints

Table 1: **Priority UN vehicle safety standards and associated existing technologies**

	Main or best estimate for modelling strategy	Sensitivity analyses
Uncertainty in estimates of road traffic injuries at baseline		
Estimates of traffic injury mortality in Latin American countries vary substantially	Overall road traffic injury incidence on the basis of global burden of disease estimates from 2016[1]	95th uncertainty interval of global burden of disease estimates from 2016,[1] and WHO's global health estimates[16]
There was no information available from the region on the distribution of crash configurations (ie, front, side, or rear) for occupant injuries	Assume distribution of crash configurations for occupant injuries from US data	Crash configurations based on data from Japan and Germany
Information on the types of vehicles involved in pedestrian injuries was available for only six countries (Argentina, Colombia, Costa Rica, Ecuador, Guatemala, and Uruguay)	For countries in which impacting vehicles for pedestrians is not known, assume average of available data	For countries in which impacting vehicles for pedestrians is not known, assume minimum and maximum estimates from available data
Uncertainty in estimates of technology penetration		
Information on the availability of technology in new vehicles sales was only available for Argentina, Colombia, Uruguay (time history data were available only from Uruguay)	Estimate prevalence of technologies of a vehicle fleet in Argentina, Colombia, and Uruguay was based on a technology adoption model for each technology that was calibrated using data from Uruguay; for other countries, assume average prevalence of these three countries	For countries in which prevalence of technologies is not known, assume minimum and maximum estimates from Argentina, Colombia, and Uruguay
Reliable seatbelt-use estimates (ie, from multi-site observational studies) were only available for eight countries (Argentina, Chile, Colombia, Costa Rica, Guatemala, Mexico, Paraguay, and Uruguay)	For countries in which seatbelt use is not known, assume average estimates from available data	For countries in which seatbelt use is not known, assume minimum and maximum estimates from available data
Uncertainty in estimates of relative risk (RR)		
There is a large variation in estimates of RR (see appendix pp 11–24) partly because of variation in quality of evaluations	For the main or best estimate, we used the mean RR estimate from the most robust evaluation; we included the maximum or minimum of the 95th CI of the RR in sensitivity analyses (the specific modelling choices for each technology)	..

Table 2: **Assumptions and sources of uncertainty in modelling strategy**

available from any source but is expected to be very low and was set at 0%.

For seatbelts, which have been available in new vehicles in most countries for many years, the relevant metric was prevalence of seatbelt use rather than seatbelt availability. We estimated prevalence of seatbelt use on the basis of a literature search for observational data in the region. Key sources of data included the 2013 and 2015 WHO Global Status Reports on Road Safety.[23,24] These reports provide data for seatbelt use for all countries from various sources. We restricted the data to countries that we could verify that estimates had been obtained from a nationally representative observational study (ie, we excluded data from expert opinion, self-report surveys, and observational studies that were done at a single location). For all technologies (including use of seatbelts), we used country data when available, and the average for other countries.

Estimating relative risks

We estimated the relative risk (ratio of probability of injuries for population exposed to vehicles with and without the technology) associated with each technology through a systematic search of the literature (including government reports). Our initial search identified 10912 articles, which were reduced to 169 articles after screening for titles and abstracts, and 40 papers after a review of the full text. To these articles, we added 19 papers identified from snowball searches and feedback from experts. The final set of 59 papers were scrutinized for the quality of analytical methods and appropriate use of controls. Estimates of effectiveness were extracted from 13 papers. The search strings, inclusion criteria, studies identified, and forest plots of relative risks for each intervention are shown in appendix pp 8–10. The final choice of relative risks are summarised in table 2.

Analytical approach

We used a comparative risk assessment framework to estimate the burden of injuries attributable to unsafe vehicles, and the proportional reduction in mortality and morbidity if the exposure to the risk factor was reduced to an alternative scenario (reduced to a counterfactual scenario). For individual vehicle technologies, the counterfactual scenario was defined as their availability in the entire fleet. For estimating the overall or combined effect of vehicle design improvements, the effects of gains from individual technologies cannot be added because their effects are not independent. Many technologies mitigate injuries in the same crash configuration (eg, seatbelts, airbags, ABS, and electronic stability control—all affect the risk of occupant injury in frontal crashes). Therefore, we estimated the overall benefits of improved vehicle design as follows: for pedestrians, we applied benefits of vehicle front-end design for pedestrian protection, which provides a conservative estimate because it ignores the benefits from other technologies, such as ABS. For motorcyclists, we applied benefits of motorcycle-ABS. For occupants, we used estimates of the annual reduction in occupant fatality risk in the USA due to vehicle design improvements, assuming that the fleet in the LAC region has safety characteristics similar to the USA in 1990.[9] To convert estimates of deaths and injuries into estimates of DALYs for the population, we

	Occupants	Non-occupants
Anti-lock braking systems (ABS)		
ABS are a braking technology available in motorcycles and four-wheeled vehicles; ABS use sensors to assess if any of the wheels are locked up during braking and reduces braking to allow the wheels to start rolling again; ABS use cycles of releasing, holding, and reapplying of brakes to prevent loss of steering control due to skidding; field tests show shorter stopping distances; in cars yaw rotation is eliminated, and steering control is maintained	RR of death for occupants of cars and light trucks in run-off-road single-vehicle and multi-vehicle crashes reported by the National Highway Traffic Safety Administration(2009);[29] automatic citation updates were disabled; RR also applied to non-fatal injuries; RR for deaths for heavy vehicle occupants in run-off-road single-vehicle and multi-vehicle crashes reported by the National Highway Traffic Safety Administration (2010);[30] RR also applied to non-fatal injuries.	RR of pedestrian death and crashes in vehicular crashes reported by the National Highway Traffic Safety Administration (2009);[29] RR of motorcyclist deaths reported by Teoh (2013);[31] RR of motorcyclist non-fatal injuries average of Spain, Italy, and Sweden reported by Rizzi et al (2015)[32]
Electronic stability control (ESC)		
ESC uses sensors to monitor the speeds of each wheel, to detect loss in traction, and to apply brakes to individual wheels and therefore help the driver to maintain control of the vehicle; ESC builds on technology used in ABS (all vehicles with ESC are also equipped with ABS)	RR of death and non-fatal injuries for car and light truck occupants were based on data from the US Department of Transportation National Highway Traffic Safety Administration (2015);[9] RR for light trucks were applied to heavy vehicles.	RR of death and non-fatal injuries for pedestrians were based on data from the US Department of Transportation National Highway Traffic Safety Administration (2015);[9] RR for motorcyclists uses motorcycle-ABS estimate reported by Teoh (2013)[31] and Rizzi et al (2015)[32]
Seatbelts		
Use of seatbelts reduce the acceleration of occupants, reduces the occupant's contact with vehicle interior, distribute forces over strongest parts of the body, and prevents ejection of the occupant from the vehicle	RR of deaths and injuries for occupants in frontal crashes reported in systematic review by Elvik (2004)[33]	..
Front airbags		
Airbags supplement seatbelts and reduces contact with vehicle interior	RR of death and non-fatal injuries for occupants in frontal crashes (average of driver and front passenger) reported by the US Department of Transportation National Highway Traffic Safety Administration (2015)[9]	..
Side airbags		
Side airbags provide a cushion for lateral impact, spreading forces, and reducing contact with vehicle interior	RR of deaths of side impacts reported by McCartt and Kyrychenko (2007)[34] for head-and-torso airbags; RR also applied to non-fatal injuries	..
Side door beam		
Side door beams aim to provide some structural integrity but have little support	RR of deaths in side-impacts reported by the US Department of Transportation National Highway Traffic Safety Administration (2015);[9] RR also applied to non-fatal injuries	..
Side structure and padding		
Strengthening side structures reduces intrusion in side impacts and energy absorbing padding cushions forces	RR of deaths in side-impacts reported by the US Department of Transportation National Highway Traffic Safety Administration (2015);[9] RR also applied to non-fatal injuries	..
Optimised system for side impact		
Teoh and Lund (2011)[7] showed that vehicles designed to ensure that airbags worked together with other design features have lower mortality risk	RR of deaths in vehicles rated good (highest rating) compared with vehicles reported poor (lowest rating) by Teoh and Lund (2011)[7]	..
Vehicle front-end design for pedestrian protection		
Designs that modify the stiffness of the bumper, hood, windshield, and A-pillar	..	RR of deaths (Strandroth, 2011)[35] and injuries (Strandroth et al, 2014)[36] for cars that are rated 3 or more stars versus zero in EuroNCAP pedestrian protection tests; applies only to impacts with cars
Overall effects of vehicle design		
An estimate of the combined effect of these technologies (note that this cannot be obtained by combining the individual estimates)	RR for occupant deaths between cars sold in the USA in 2015 versus 1990 based on the US Department of Transportation National Highway Traffic Safety Administration (2015);[9] RR also applied to non-fatal injuries	RR for pedestrian deaths (Strandroth, 2013)[35] and non-fatal injuries (Strandroth et al, 2011);[36] applies only to impacts with cars; RR for motorcycle deaths (Teoh and Lund, 2011)[7] and non-fatal injuries (Rizzi et al, 2015)[32] for motorcycle-ABS

Table 3: **Technology-specific modelling choices for vehicle safety technologies**

calculated DALYs using a previously described burden calculator.[25]

Sensitivity analysis

As described above, our analysis required many assumptions, which are summarised in table 2. Furthermore, there was substantial uncertainty associated with various model inputs. We characterised this uncertainty by doing a sensitivity analysis that was based on recalculating results under alternative modelling assumptions. We reported the minimum and maximum values derived from modelling all possible combinations of the following variations to the main estimates: (1) baseline traffic injury estimates: we used maximum

	Argentina	Brazil	Colombia	Ecuador	Mexico	Uruguay	LAC region
Road traffic deaths in 2016							
Pedestrian	646	14 182	2011	1161	9193	98	39 653
Bicyclist	129	1969	343	77	799	17	4320
Motorcyclist	1939	15 713	3040	1161	2451	330	30 444
Occupant	3232	16 125	522	890	7451	161	38 189
Others	517	735	947	581	458	16	4944
Total	6463	48 724	6863	3871	20 351	623	117 551
Estimates of deaths averted (sensitivity analysis range)							
ABS	9·0% (2·7–15·5)	10·6% (3·3–19·2)	14·0% (3·4–23·2)	9·7% (3·0–17·8)	7·8% (3·0–14·1)	11·7% (3·6–24·6)	9·6% (3·1–17·4)
ESC	20·9% (9·8–34·0)	20·7% (8·7–33·1)	18·1% (6·4–30·4)	17·7% (7·2–28·5)	17·8% (8·8–28·6)	24·0% (8·3–36·9)	19·4% (8·6–31·1)
Seatbelt	19·9% (13·9–23·9)	12·3% (9·2–15·8)	2·4% (2·1–3·6)	9·8% (6·4–11·0)	15·4% (10·2–17·5)	8·5% (7·2–12·4)	12·1% (9·1–15·5)
Airbag-front	4·9% (2·8–6·7)	3·6% (1·9–4·4)	0·9% (0·4–1·0)	2·5% (1·3–3·1)	4·0% (2·1–4·9)	3·0% (1·5–3·5)	3·5% (1·8–4·3)
Airbag-side	4·3% (2·5–5·2)	2·9% (1·7–3·5)	0·6% (0·4–0·8)	2·0% (1·2–2·4)	3·2% (1·8–3·8)	2·3% (1·3–2·7)	2·8% (1·6–3·4)
Side door beam	0·2% (0·1–0·3)	0·1% (0·1–0·2)	0%	0·1% (0·0–0·1)	0·2% (0·1–0·2)	0·1% (0·0–0·2)	0·1% (0·1–0·2)
Side structure and padding	2·5% (1·3–3·2)	1·6% (0·8–2·1)	0·4% (0·2–0·5)	1·1% (0·6–1·5)	1·8% (0·9–2·4)	1·3% (0·7–1·7)	1·6% (0·8–2·1)
Side-impact optimisation	9·7% (4·8–10·0)	6·4% (3·2–6·6)	1·5% (0·7–1·5)	4·5% (2·2–4·6)	7·1% (3·5–7·3)	5·1% (2·5–5·2)	6·3% (3·1–6·5)
Vehicle front-end (pedestrian protection)	1·7% (0·7–3·1)	5·2% (1·9–9·0)	3·4% (1·9–9·0)	5·8% (2·0–9·2)	8·1% (3·0–13·9)	3·0% (1·0–4·8)	6·0% (2·2–10·4)
Overall	32·7% (16·0–42·7)	29·5% (13·2–41·1)	20·4% (7·7–34·2)	25·0% (10·5–35·2)	27·6% (13·4–38·1)	30·6% (12·3–43·4)	28·1% (12·8–39·2)

ABS= antilock-brake systems. ESC=electronic stability control. LAC=Latin America and the Caribbean

Table 4: **Estimates of the effect of improving vehicle design on road traffic deaths in six countries and the LAC region**

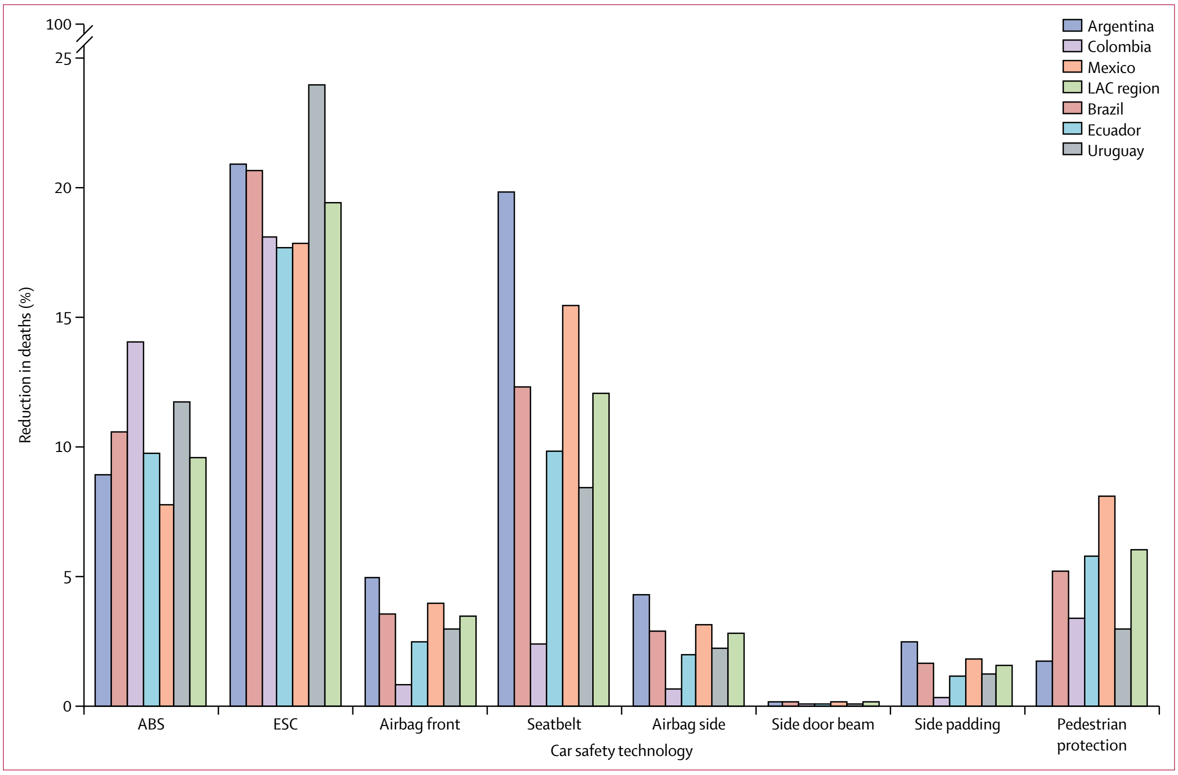

Figure: **Mortality reduction in Argentina, Brazil, Colombia, Ecuador, Mexico, Uruguay, and the Latin America and the Caribbean region by car safety technology**
ABS=antilock-brake systems. ESC=electronic stability control. LAC=Latin America and the Caribbean.

and minimum values of the 95th uncertainty interval of road injuries reported in the 2016 GBD,[26] and WHO's Global Health Estimates;[16] (2) crash configuration: we used the percentage of occupant injuries resulting from frontal, side, and rear impact crashes in Germany,[27] and Japan;[28] (3) technology penetration (including availability

	Argentina	Brazil	Colombia	Ecuador	Mexico	Uruguay	LAC Region
DALYs lost to road traffic injuries in 2016							
Pedestrian	39898	856924	133741	70803	615077	5197	2506516
Bicyclist	8026	119627	22948	4731	53709	936	274306
Motorcyclist	118869	944674	200926	70414	162714	17423	1912278
Occupant	228916	1089869	40363	60470	571020	9746	2733641
Others	33335	45905	65914	36504	31858	899	324088
Total	429044	3057000	463892	242922	1434377	34200	7750830
Estimates of DALYs averted (sensitivity analysis range)							
ABS	7·7% (2·1–14·3)	9·1% (2·1–18·1)	11·9% (1·8–22·3)	8·4% (1·8–16·8)	5·5% (0·7–12·3)	10·5% (2·8–23·8)	7·8% (1·6–16·1)
ESC	19·1% (8·3–31·6)	18·7% (6·4–31·4)	15·8% (3·5–29·2)	15·9% (5·2–27·3)	14·7% (4·5–26·0)	22·3% (6·9–35·7)	17·0% (5·7–29·2)
Seatbelt	20·2% (14·1–24·5)	12·7% (9·5–16·5)	2·6% (2·3–4·0)	10·3% (6·6–11·5)	16·1% (10·5–18·3)	8·9% (7·5–13·1)	12·6% (9·4–16·3)
Airbag-front	4·2% (3·0–7·1)	3·2% (2·0–4·7)	0·8% (0·5–1·2)	2·3% (1·4–3·3)	3·4% (2·3–5·3)	2·6% (1·6–3·8)	3·1% (2·0–4·7)
Airbag-side	5·2% (1·9–6·3)	3·4% (1·4–4·1)	0·8% (0·3–1·0)	2·4% (1·0–2·9)	3·9% (1·4–4·7)	2·8% (1·1–3·4)	3·4% (1·3–4·1)
Side door beam	0·2% (0·1–0·4)	0·2% (0·0–0·2)	0% (0·0–0·1)	0·1% (0·0–0·2)	0·2% (0·0–0·3)	0·1% (0·0–0·2)	0·2% (0·0–0·2)
Side structure and padding	3·0% (1·0–3·9)	1·9% (0·7–2·5)	0·5% (0·2–0·6)	1·4% (0·5–1·8)	2·2% (0·7–2·9)	1·6% (0·5–2·1)	1·9% (0·7–2·5)
Side-impact optimisation	11·7% (3·7–12·1)	7·7% (2·7–7·9)	1·9% (0·6–2·0)	5·3% (1·9–5·5)	8·7% (2·8–9·0)	6·3% (2·0–6·4)	7·7% (2·5–7·9)
Vehicle front-end (pedestrian protection)	1·6% (0·6–2·9)	5·0% (1·8–8·6)	3·3% (1·9–8·9)	5·6% (1·9–9·0)	7·7% (2·8–13·2)	2·9% (1·0–4·7)	5·8% (2·1–10·0)
Overall	33·1% (16·9–43·3)	29·9% (13·9–41·7)	20·3% (8·3–34·6)	25·2% (11·0–35·7)	28·3% (14·1–38·8)	30·7% (13·2–44·1)	28·6% (13·5–39·8)

ABS=antilock-brake systems. DALY=disability-adjusted life year. ESC=electronic stability control. LAC=Latin America and Caribbean.

Table 5: **Estimates of the effect of improving vehicle design on health loss (disability adjusted life years lost) due to road traffic crashes in six countries in the LAC region**

and use of seatbelts): for countries for which data on penetration of a particular technology was not available, we used the maximum and minimum values for other countries; and (4) relative risks: we included the maximum and minimum values of the 95th CI of the relative risk reported in the studies selected from the systematic review. For the overall effect of vehicle design improvements, we additionally modelled baseline fleet safety characteristics as similar to the US vehicle fleet in 1980 and 2000.

Role of the funding source
The funder approved the study design and helped to connect with national agencies that provided data. The funder of the study had no role in study design, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results
Our findings suggest that increasing the availability of selected vehicle safety technologies will have a large effect on reducing road traffic deaths and DALYs in the LAC region. Tables 3 and 4, and the figure, summarise the estimated effect of vehicle safety technologies on lives saved and DALYs averted in the six focus countries (Argentina, Colombia, Costa Rica, Ecuador, Guatemala, and Uruguay) and the LAC region.

Increasing use of motorcycle-ABS would have a large benefit for motorcyclists, resulting in 21% fewer motorcyclist deaths in the region. Similarly, increasing use of four-wheeler ABS would provide large benefits for pedestrians (8·5% fewer deaths). The gains would be smallest for occupants. The overall effect was 10% (sensitivity analysis range 3·1%–17·4%; table 4) fewer road traffic deaths and 8% (1·6–16·1; table 5) fewer DALYs in the LAC region. These benefits were largest for countries (eg, Colombia) that had a high incidence of motorcyclist and pedestrian injuries. In addition to the large benefits to motorcyclists and pedestrians from ABS, electronic stability control would provide large benefits for occupants. Full penetration of electronic stability control in the vehicle fleet would result in 19% (8·6–31·1) fewer deaths and 17% (5·7–29·2) fewer DALYs in the region.

Seatbelts provided large benefits to occupants but had no effect on non-occupant injuries (eg, injuries sustained by pedestrians, bicyclists, and motorcyclists). Increasing seatbelt use would reduce deaths by 12% (sensitivity analysis 9·1–15·5) and DALYs by 13% (9·4–16·3) in the LAC region, but these estimates vary substantially for countries. For example, Argentina, which had a large proportion of occupant injuries and relatively low (compared to high-income countries) use of seatbelts, overall DALYs would be reduced by 20% (14·1–24·5), in contrast with Colombia, where DALYs would be reduced by only 3% (2·3–4·0). Similarly, frontal airbags only provided protection to occupants. However, frontal airbags were less effective at reducing injuries than seatbelts and were already commonly available in vehicles. As a result, increasing penetration of frontal airbags would result in only 4% (1·8%–4·3%) fewer deaths and 3% (2·0–4·7) fewer DALYs in the LAC region.

Of the three side-impact technologies assessed, side door beams would have the least effect, with reductions in deaths and DALYs of less than 0·5%, even in countries in which occupant injuries are dominant. Side structure and padding, and side airbags were more beneficial than side door beams, with reductions in DALYs of 2% (sensitivity analysis range 0·7%–2·5%) for side structure and padding, and 3% (1·3–4·1) for side airbags, in the LAC region. However, developing a system for side impact protection, in which individual technologies are optimised to work together, would have large benefits. Increasing the availability of such vehicles would result in 6% (3·1–6·5) fewer deaths in the region. In Argentina, where occupant injuries are common, there would be 10% (4·8–10·0) fewer deaths.

Improving vehicle front-end design for pedestrian protection would result in large gains for pedestrians (ie, 18% fewer pedestrian deaths in the LAC region). In countries where pedestrian injuries dominate, overall DALYs lost to traffic injuries would be reduced. For instance, in Mexico, DALYs would be reduced by 8% (sensitivity analysis range 2·8%–13·2%) but the gains in Argentina, Colombia, and Uruguay, where a smaller proportion of traffic injuries involve pedestrians, would be less than half that in Mexico. In the LAC region, improving vehicle front-end design would result in 6% (2·1–10·0) fewer DALYs. These estimates do not account for the potential spillover benefits to bicyclists and motorcyclists.

Our estimates suggest large overall reductions in deaths and DALYs from improvements in vehicle design in all countries analysed. The gains are highest for Argentina (33% fewer DALYs) and lowest for Colombia (20% fewer DALYs). In the LAC region, improving vehicle design would result in 28% (sensitivity analysis range 12·8%–39·2%) fewer deaths, and 29% (13·5%–39·8%) fewer DALYs.

Discussion

We showed that the wide availability of proven vehicle safety technologies would result in large gains in the LAC region and LMIC, more generally. Notably, our analysis restricts attention to technologies that have been available for many years in HICs, and whose real-world effects have been established. In fact, there are many emerging technologies that hold great promise, including some, such as automatic emergency braking[37] and lane departure warning,[38] that evaluations suggest will have large beneficial effects.

In particular, we find that increasing availability of electronic stability control, which build on ABS, would provide the largest benefits. Although evaluations of ABS for occupant safety have shown mixed results (ie, the benefits for occupants are not proven), ABS provide modest benefits for pedestrians.[9] Motorcycle-ABS, in particular, are one of the few vehicle technologies that have large benefits for motorcyclists, who make up the largest share of traffic deaths in many LMICs in the region (eg, Colombia and Uruguay) and globally.[5] Similarly, improving the crashworthiness of cars will have a large benefits for countries in which occupants comprise a large proportion of traffic injuries (eg, Argentina). Seatbelts are a highly effective technology that are already available in almost all vehicles in the region, but seatbelt use is low. The LAC region needs to strengthen the enforcement of belt use laws to derive the benefits of this technology. Finally, although vehicle front-end design has a large effect on pedestrian injuries,[36,35] regulations apply only to the design of cars. However, unlike HICs, where cars are the primary threat to pedestrians, in most LMICs, pedestrians are killed in crashes with other vehicles, especially buses and trucks, which need to be included in such regulatory efforts.

There is substantial uncertainty in our estimates due to the uncertainty in inputs (summarised in table 2), not all of which could be modelled. Notably, the 2016 GBD[26] and WHO's global health estimates[16] provide differing estimates of the national incidence of traffic injuries in the region, which we model in our sensitivity analysis. Data for the distribution of crash configurations (eg, front, side, rear, and rollover) were not available from any countries in the region. Therefore, we used data for crash configurations from the USA for our main estimates and included data from Germany and Japan in the sensitivity analysis. Although crash configurations in these two countries did not differ substantially from the USA, it is possible that differences in crash configuration would be larger in countries with less developed highway infrastructure. There are very little available data in the region on the prevalence of vehicle design technologies. Our analysis used the range of prevalence estimates from only three countries to generate estimates for the entire region. Finally, our analysis assumes that the benefits of these technologies in the LAC region would be similar to those in HICs where their effects on safety were evaluated. Although we model the uncertainty in relative risks reported in these evaluations, it is important to note that deriving the full benefits of technologies often requires supportive structural design. For instance, the effectiveness of an airbag at preventing injuries depends on whether seatbelts are being used.[9] Airbag and seatbelts are also more effective when crashworthiness design of the vehicle front-end ensures that the passenger compartment does not collapse. Therefore, although our analysis focuses on assessing the effect of technologies, the purpose of the analysis is not to promote particular technologies but to encourage regulatory efforts that will improve overall vehicle safety design.

Our finding of the large benefits of improving vehicle design raises an important question: what motivated manufacturers to improve vehicle design in HICs? There are two policy mechanisms that have driven advances in vehicle safety in HICs.[39] First, regulations were instituted that required all cars that were sold to provide a minimum threshold of safety. Second, HICs established NCAPs that tested cars in conditions that were more stringent than regulations and change more often than regulations. Safety ratings from NCAPs had a large influence on consumer choices and created strong market forces for manufacturers to improve safety design. In fact, there is strong evidence from the USA and Europe that car manufacturers respond to changing NCAP test requirements by redesigning cars to be safer.[7,39,40] Typically, these engineering efforts have involved the development of safety technologies and optimising how they work together to provide the maximum safety benefits. For instance, auto manufacturers responded to new NCAP tests in the USA by design modifications that reduced the probability of death in side impacts by 70%.[7] As our analysis highlights, the benefit from the optimised response far exceeds the benefits of the individual side impact technologies.

The time it takes for new technology to become pervasive in the vehicle fleet is much shorter in rapidly motorising countries. Contrary to popular belief, the vehicle fleet in LMICs tends to be young. Based on our fleet evolution model, almost three-quarters of vehicles in use in the LAC region are less than 10 years old. In fact our analysis suggests that if vehicle safety technologies had been introduced in all new cars at the start of the UN Decade of Action for Road Safety (2011–20), by now there would be approximately 21% fewer traffic deaths in the LAC region, leaving this region much closer to SDG 3.6 of halving traffic deaths by 2020.

Contributors
KB contributed to the study design and led all aspects of the study, including literature review, acquisition of data, data analysis, and wrote the first draft of the Article. KG contributed to study design and did the analysis. Both authors contributed to the discussion and interpretation of the results and to the writing of the manuscript. Both authors have read and approved the final manuscript.

Declaration of interests
We declare no competing interests.

Acknowledgments
This study was funded by the Inter-American Development Bank. We thank a team of student researchers for their assistance with the literature review. We thank our advisory group (Dinesh Mohan, Brian O'Neill, Dipan Bose, and Maria Segui Gomez) for their feedback on the study's design, inputs, and findings. This study was supported by funding from the Inter-American Development Bank, which has worked to support the adoption of UN safety regulations in the LAC region.

References
1 Hay SI, Abajobir AA, Abate KH, et al. Global, regional, and national disability-adjusted life-years (DALYs) for 333 diseases and injuries and healthy life expectancy (HALE) for 195 countries and territories, 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016. *Lancet* 2017; **390:** 1260–344.

2 International Transport Forum. Road safety annual report—2018. 2018. Paris, France: The Organisation for Economic Co-operation and Development Publishing. https://www.itf-oecd.org/road-safety-annual-report-2018 (accessed April 29, 2020).

3 WHO. World report on road traffic injury prevention. Geneva: World Health Organization, 2004.

4 International Transport Forum. Zero road deaths and serious injuries. 2016. Paris, France: The Organisation for Economic Co-operation and Development Publishing. https://www.oecd.org/publications/zero-road-deaths-and-serious-injuries-9789282108055-en.htm (accessed April 29, 2020).

5 WHO. Global status report on road safety 2018. Geneva: World Health Organization, 2018.

6 Farmer CM, Lund AK. The effects of vehicle redesign on the risk of driver death. *Traffic Inj Prev* 2015; **16:** 684–90.

7 Teoh ER, Lund AK. IIHS side crash test ratings and occupant death risk in real-world crashes. *Traffic Inj Prev* 2011; **12:** 500–07.

8 National Highway Traffic Safety Administration. An analysis of recent improvements to vehicle safety. 2012. Washington, DC. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/811572 (accessed April 29, 2020).

9 US Department of Transportation National Highway Traffic Safety Administration. Lives saved by vehicle safety technologies and associated federal motor vehicle safety standards, 1960 to 2012–Passenger cars and LTVs. 2015. Washington, DC. https://www-esv.nhtsa.dot.gov/proceedings/24/files/24ESV-000291.PDF (accessed April 29, 2020).

10 Chisholm D, Naci H, Hyder AA, Tran NT, Peden M. Cost effectiveness of strategies to combat road traffic injuries in sub-Saharan Africa and South East Asia: mathematical modelling study. *BMJ* 2012; **344:** e612.

11 Mock CN, Nugent R, Kobusingye O, Smith KR. Interventions to prevent injuries and reduce environmental and occupational hazards: a review of economic evaluations from low- and middle-income countries. In: Watkins D, Dabestani N, Nugent R, Levin C, eds. Disease control priorities, third edn (vol 7): injury prevention and environmental health. Washington, DC: World Bank, 2017: 199–211.

12 Vecino-Ortiz AI, Hyder AA. The use of cost-benefit analysis in road assessments: a methodological inquiry. *Inj Prev* 2014; **20:** 50–53.

13 Kassim KAA, Furas A, Mustaffa S. How the market reacts to NCAP in emerging countries? *J Soc Automot Eng Malayas* 2017; **1:** 272–76.

14 International Research Council on the Biomechanics of Injury. Saving lives with safer cars: the past, present and future of consumer safety ratings. 2016. http://www.ircobi.org/wordpress/downloads/irc16/pdf-files/01.pdf (accessed April 29, 2020).

15 Global NCAP. Democratising car safety: road map for safer cars 2020. 2015. www.globalncap.org (accessed April 29, 2020).

16 WHO. Global Health Observatory. Sept 7, 2019. https://www.who.int/gho/en/ (accessed April 29, 2020).

17 Bhalla K, Shotten M, Cohen A, et al. Transport for health: the global burden of disease due to injuries and air pollution from motorized road transport. 2014. Washington, DC: World Bank Global Road Safety Facility, and Institute for Health Metrics and Evaluation. http://www.healthmetricsandevaluation.org/gbd/publications/policy-report/transport-health-global-burden-disease-motorized-road-transport (accessed April 29, 2020).

18 Bhalla K, Harrison JE, Shahraz S, Fingerhut LA. Availability and quality of cause-of-death data for estimating the global burden of injuries. *Bull World Health Organ* 2010; **88:** 831–838.

19 US National Highway Traffic Safety Administration. Fatality analysis reporting system (FARS). Sept 7, 2019. National Highway Traffic Safety Administration. https://www.nhtsa.gov/research-data/fatality-analysis-reporting-system-fars (accessed April 29, 2020).

20 AUTODATA. Una empresa consultora especializada en datos del sector automotriz. Sept 7, 2019. https://autodata.com.uy/ (accessed April 29, 2020).

21 Huo H, Wang M. Modeling future vehicle sales and stock in China. *Energy Policy* 2012; **43:** 17–29.

22 Greenspan A, Cohen D. Motor vehicle stocks, scrappage, and sales. *Rev Econ Stat* 1999; **81:** 369–83.

23 WHO. Global status report on road safety—supporting a decade of action. Geneva: World Health Organization, 2013.

24 WHO. Global status report on road safety 2015. Geneva: World Health Organization, 2015.

25 Bhalla K, Harrison JE. Burden calculator: a simple and open analytical tool for estimating the population burden of injuries. *Inj Prev* 2016; **22** (suppl 1)**:** i23–26.

26 Naghavi M, Abajobir AA, Abbafati C, et al. Global, regional, and national age-sex specific mortality for 264 causes of death, 1980–2016: a systematic analysis for the Global Burden of Disease Study 2016. *Lancet* 2017; **390:** 1151–210.

27 Eis V, Sferco R, Fay P. A detailed analysis of the characteristics of European rear impacts. Proceedings of the International Technical Conference on the Enhanced Safety of Vehicles; Washington, DC; June 6–9, 2005.

28 Institute for Traffic Accident Research and Data Analysis. Collisions with roadside structures. 2010. https://www.itarda.or.jp/english/itardainfomation/info82/82top.html (accessed April 29, 2020).

29 National Highway Traffic Safety Administration. The long-term effects of ABS in passenger cars and LTVs. Washington, DC. US Department of Transportation National Highway Traffic Safety Administration. 2009. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/811182 (accessed April 29, 2020).

30 National Highway Traffic Safety Administration. The effectiveness of ABS in heavy truck tractors and trailers. Washington, DC. US Department of Transportation National Highway Traffic Safety Administration. 2010. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/811339 (accessed April 29, 2020).

31 Teoh ER. Effects of antilock braking systems on motorcycle fatal crash rates: an update May 2013. Insurance Institute for Highway Safety. 2013. https://www.iihs.org/api/datastoredocument/bibliography/2042 (accessed April 29, 2020).

32 Rizzi M, Strandroth J, Kullgren A, Tingvall C, Fildes B. Effectiveness of motorcycle antilock braking systems (ABS) in reducing crashes, the first cross-national study. *Traffic Inj Prev* 2015; **16:** 177–83.

33 Elvik R, Høye A, Vaa T, Sørensen M. Vehicle design and protective devices. In: Elvik R, Vaa T, eds. The handbook of road safety measures. Bingley, UK: Emerald, 2009: 543–690.

34 McCartt AT, Kyrychenko SY. Efficacy of side airbags in reducing driver deaths in driver-side car and SUV collisions. *Traffic Inj Prev* 2007; **8:** 162–70.

35 Standroff J. Correlation between pedestrian injury severity in real-life crashes and Euro NCAP pedestrian test results. *Traffic Inj Prev* 2011; **12:** 604–13.

36 Strandroth J, Sternlund S, Lie A. Correlation between Euro NCAP pedestrian test results and injury severity in injury crashes with pedestrians and bicyclists in Sweden. *Stapp Car Crash J* 2014; **58:** 213–31.

37 Cicchino JB. Effectiveness of forward collision warning and autonomous emergency braking systems in reducing front-to-rear crash rates. *Accid Anal Prev* 2017; **99:** 142–52.

38 Cicchino JB. Effects of lane departure warning on police-reported crash rates. *J Safety Res* 2018; **66:** 61–70.

39 O'Neill B. Preventing passenger vehicle occupant injuries by vehicle design—a historical perspective from IIHS. *Traffic Inj Prev* 2009; **10:** 113–26.

40 Kullgren A, Lie A, Tingvall C. Comparison between Euro NCAP test results and real-world crash data. *Traffic Inj Prev* 2010; **11:** 587–93.