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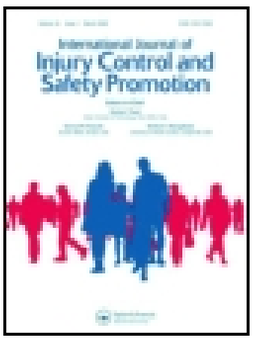

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Effectiveness of interventions to prevent motorcycle injuries: systematic review of the literature

Miguel Araujo[a], Eduardo Illanes[b], Evelina Chapman[c] and Eugênia Rodrigues[c]*

[a]*Public Health School, Universidad Mayor, Santiago, Chile;* [b]*Medical School Faculty, Barros Luco Hospital Complex, Universidad Mayor, Santiago, Chile;* [c]*Pan American Health Organization/World Health Organization, Washington, DC, USA*

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Globally, 49% of deaths from traffic crashes occur among vulnerable road users, including pedestrians, bicyclists, and motorcyclists. Approximately, a quarter of those killed are motorcyclists. The authors carried out a systematic review of the literature to evaluate the effectiveness of interventions to prevent motorcycle crashes and the associated morbidity and mortality. The studies included in this review provide evidence for the effectiveness of helmet use, protective clothing, training, and penalties for alcohol consumption and speeding in preventing injury and death to motorcyclists. The use of helmets is effective, especially if it is universally required by law for drivers and passengers. Training to obtain a license also has positive effects but not when it is totally voluntary. There is limited but consistent evidence that strengthening laws for penalties related to alcohol consumption or speeding has an impact on risk. Traffic calming interventions could help reduce crashes in urban areas. In jurisdictions where there is limited regulation or adherence to effective measures, such as the use of helmets, efforts should be directed primarily at expanding such practices. In other areas, efforts can focus on approaches based on alternative effective measures or on more innovative interventions adapted to local conditions.

Keywords: systematic review; motorcycles; road traffic injury; vulnerable road user; motorcycle user

Introduction

The global rate for road traffic deaths is 17.5 per 100,000 population and nearly a quarter of all road traffic deaths are among motorcyclists. However, this is disproportionately distributed across the world, with South-East Asian Region and Western Pacific Region each accounting for 34% of the world's motorcyclist deaths compared to the African Region which account for 7%. (World Health Organization [WHO], 2015). In the Region of the Americas, the proportion of road traffic deaths among motorcyclists is on the rise – increasing from 15% to 20% between 2010 and 2013. (Hidalgo, 2011; Law No. 12.436 [Brazil], 2011; Pan American Health Organization [PAHO], 2016). Proportionately, motorcycle users are involved in more crashes and are more likely to suffer fatal injuries than users of other motor vehicles (Lin & Kraus, 2009; Monk, Buckley, & Dyer, 2009).

Evidence-based studies indicate the use of helmets is the best prevention method for crash morbidity and mortality. In many Latin America and the Caribbean (LAC) countries, the situation with regard to the use of helmets is unknown; however, countries with data reported usage percentages varying from less than 10% to over 90% (PAHO, 2009).

A best practice on helmet law applies to all passengers, of all ages, on all roads and on all engine types, and includes an international or national standard for helmets. Globally, 94% of the countries have a national law that require the use of helmets among motorcyclists, there are a large number of countries where loopholes in these laws potentially limit their effectiveness (WHO, 2015). Jamaica, as an example, has legislation that is comprehensive and broad in scope, yet the reported helmet use is less than 10% (Cawich, Harding, Evans, Crandon, & Martín, 2010).Enforcement of helmet laws is critical to their effectiveness.

Of the 104 measures addressed in *Countermeasures That Work* (2011) – guidelines issued by the US National Highway Traffic Safety Administration to design prevention strategies – the helmet use requirement is the only measure proven to be effective for motorcycle users (Goodwin et al., 2013; Preusser, Williams, Nichols, Tison, & Chaudhary, 2008). The United Nations' *Decade of Action for Road Safety 2011–2020* additionally recommends improving road infrastructure, especially for the most vulnerable users, and encourages the use of safety technologies such as anti-lock brakes (Peden et al., 2004; Racioppi, Eriksson, Tingvall, & Villaveces, 2004; WHO, 2011).

Research on traffic crashes is highly 'context-dependent' because variables that are specific to local

*Corresponding author. Email: rodrigem@paho.org

conditions can modify the effects or the applicability of measures. For example, motorcyclists in tropical countries may be less likely to wear protective clothing because of the heat. Furthermore, the extent to which a law is enforced, and not only the contents of the law itself, can be the main factor that explains the impact of an intervention.

A meta-analysis of 36 studies on interventions focusing on high-risk points ('black spots') found that the lack of control of confounding variables was associated with an overestimation of the effects of interventions (Elvik, 1997). The studies without adjustment reported greater effectiveness, and when simultaneous controls were applied to the principal sources of bias (previous trends, regression to the mean, and migration of crashes), no statistically significant effects were observed.

The evaluation of preventive interventions can focus on a specific measure or on more complex forms of implementation. One level of evaluation is of *strategic plans* for injury prevention among motorcyclists. Evaluation of *laws* is possible, particularly when referring to a specific intervention, such as helmet use or speed limit. Studies from experiences of the United States and Australia analysed time series in several states using common output variables, covariable adjustment (for example, other laws/regulations, socio-economic factors, or alcohol consumption rates), and control groups of states that did not adopt similar laws (Fell & Voas, 2006). The evaluation of *specific interventions*, such as educational interventions, is best adapted to more traditional designs, randomized controlled trials, or quasi-experimental studies. Finally, *in-depth analysis* of a series of events, which includes a detailed, on-site collection of the factors that could play a role in the cause of a crash, can be processed through descriptive techniques or analytical methods.

Road traffic injuries related to motorcycle use are an emerging problem requiring a complex approach. Countries must implement effective measures that have been adapted to their realities. This systematic review aims to summarize the best available scientific evidence from studies conducted worldwide on the effectiveness of interventions to prevent motorcycle-related injuries, and to support decision-making on the subject.

Methods

Inclusion and exclusion criteria of the studies

Studies available in English, Spanish, or Portuguese were included. Studies were selected based on whether they evaluated the effectiveness of preventive interventions for motorcycle crashes or traffic crashes in general (in the case of the latter, the study had to make it possible to analyse results for motorcycles apart from other vehicles). Only studies that provided objective measurements on the frequency of crashes or their effects in terms of mortality, injuries or sequelae were included.

Design

Systematic reviews were selected that included a description of the bibliographic search methods and the criteria for eligibility of the studies. These reviews were complemented by original research published since 2000, including randomized controlled trials, quasi-randomized trials, quasi-experimental studies, interrupted time series, uncontrolled before-after studies, and analytical observational studies (cohorts, case-control, analytical cross-sectional studies). It was assumed that relevant studies prior to 2000 would already be incorporated in the systematic reviews selected.

Process of search and selection of the studies

An online search was carried out on MEDLINE; Lilacs; SciELO; Embase; Database of Abstracts of Reviews of Effects (DARE); Health Technology Assessment (HTA) Database; National Health Service (United Kingdom) Economic Evaluation Database (NHS EED); the Cochrane Central Library; PAHO/WHO library database (WHOLIS); TRID (the Transport Research Board's Transportation Research Information Services (TRIS) and the Organisation for Economic Co-operation and Development's (OECD) Joint Transport Research Centre's International Transport Research Documentation (ITRD) database); websites of WHO and PAHO; Centers for Accident Research and Road Safety, Queensland (Australia) (CARRS-Q); and the Global Road Safety Forum (GRSF). A search for grey literature was carried out on Google Scholar, and the reference lists of the selected articles and complementary documents (reports of organizations and theses) were reviewed. Added to this was a 'snowball' strategy to search related articles on the databases and search engines. The search extended to all sources available as of February 2012.

Key words used were: motorcycles[mh], motorcycle [tw], motorbike[tw], moped[tw], scooter[tw], 'Accidents, Traffic' [mh] (MEDLINE-PubMed), variants in Spanish and Portuguese, and adaptations for other databases.

The authors used filters for systematic reviews from the National Library of Medicine for PubMed (based on Shojania & Bero, 2001) and filters for original research studies adapted from the Cochrane Highly Sensitive Search Strategy for identifying randomized trials in MEDLINE (Higgins & Green, 2011). These were complemented by strategies developed by the authors to identify nonrandomized intervention studies and observational analytical studies. Detailed strategies are available on request from the authors.

Critical appraisal

Two independent reviewers analysed the quality of the selected studies. The systematic reviews were evaluated

using the AMSTAR instrument (Shea et al., 2007). The studies on effectiveness were evaluated through a set of criteria adapted from the Cochrane Effective Practice and Organization of Care Review Group's (EPOC) Data Collection Checklist and the Critical Appraisal Skills Programme (CASP) for interrupted time series, longitudinal, uncontrolled before-after, case-control, and analytical cross-sectional studies.

Extraction of data and summary of results

For each systematic review, the authors extracted its objectives, methodological quality, search period, quantity and type of selected studies, presence of studies of LAC, participants in or characteristics of the groups, interventions, output variables, and results. In the case of original research, the context of the study, its design and sample size, interventions, and results were extracted. For each type of intervention evaluated, tables and narrative summaries were prepared to include results of the critical analysis and of the characteristics and results of the studies. Estimations combining the specific effects of the selected reviews were not carried out. The principal output variables considered in the analysis were rates of crashes, mortality, injuries, and subcategories of these (for example, by part of the anatomy or severity of injury), in the manner originally reported by the authors of the studies (RR, OR). Confidence intervals were provided when available.

Results

Results of the bibliographic search

Of the 3559 initial references, 81 were preselected based on information from titles and summaries. The full texts of this group were examined in order to obtain a final total of 20 studies. Eleven were systematic reviews (Ameratunga, Hijar, & Norton, 2006; Bellefleur & Gagnon, 2011; Byrnes & Gerberich, 2012; Daniello, Gabler, & Mehta, 2009; Errington et al., 2006; Horberry, Hutchins, & Tong, 2008; Kardamanidis, Martiniuk, Ivers, Stevenson, & Thistlewaite, 2010; Liu et al., 2008; MacLeod, Digiacomo, & Tinkoff, 2010; Morrison, Petticrew, & Thompson, 2003; Novoa, Pérez, & Borrell, 2009) and nine were original research studies (Cunha & Gonçalves, 2001; de Rome et al., 2011; Espitia-Hardeman et al., 2008; French, Gumus, & Homer, 2009; Novoa, Pérez, Santamariña-Rubio, & Borrell, 2011; Pérez et al., 2009; Teoh, 2010; Villaveces et al., 2003; Yu, Chen, Chiu, & Lin, 2011).

Characteristics of the studies

The principal characteristics of the original research studies selected are detailed in Tables 1 and 2.

Of the 11 reviews (Table 3), two are Cochrane systematic reviews on helmet use (Liu et al., 2008) and driver training (Kardamanidis et al., 2010). Three are reviews that compile previous systematic reviews (Errington et al., 2006; Novoa et al., 2009; Morrison et al., 2003). The remaining six reviews were of poor or moderate quality, lacked adequate explanations of the methods used or selection criteria, and/or were limited to studies of developed countries (Ameratunga et al., 2006; Bellefleur & Gagnon, 2011; Byrnes & Gerberich, 2012; Daniello et al., 2009; Horberry et al., 2008; MacLeod et al., 2010).

The preventive measures analysed in these reviews include the use of helmets, different types of helmets, universal and partial laws on helmet use, training before and after obtaining a license, traffic calming (used to reduce the speed of vehicles), measures to lessen driver fatigue, improved visibility of the motorcycle or the driver (daytime running lights, fluorescent jackets), motorcycle design, restrictions on engine displacement, an increase in the minimum age required to obtain a license, restrictions on nocturnal use, and graduated licensing.

The nine original research studies (Table 4) selected were observational. They included a case-control study (Yu et al., 2011), two cross-sectional analytical studies (de Rome et al., 2011; Teoh, 2010), three interrupted time series studies (Espitia-Hardeman et al., 2008; Novoa et al., 2011; Pérez et al., 2009), an uncontrolled before–after study (Cunha & Gonçalves, 2001), and two longitudinal studies (French et al.,2009; Villaveces et al., 2003). The longitudinal studies analyse aggregate data series over the course of a time period in multiple states in the United States and evaluate their association with legal measures. Two of the studies were conducted in countries of LAC (Cunha & Gonçalves, 2001; Espitia-Hardeman et al., 2008).

Most of the original research studies use some covariable adjustment method. The study by Yu et al. (2011) uses controls matched for the time of the crash in order to control for environmental conditions and adjusts for other variables using multivariate techniques. Of the cross-sectional studies, only the one by de Rome et al. (2011) makes an adjustment for covariables and an analysis of sensitivity using a driver subgroup. Teoh (2010) compares the basal frequency of some risk factors among the groups. The time series studies (Espitia-Hardeman et al., 2008; Novoa et al., 2011; Pérez et al., 2009) incorporate the trends and seasonality of the series before and after the intervention, and make adjustments for some variables through multivariate methods or stratified analyses. The Cunha and Gonçalves (2001) study is the weakest due to the lack of adjustment and the limited time period considered by the measurements. The longitudinal studies by Villaveces et al. (2003) and French et al. (2009) include multivariate adjustment of the results related to traffic and the risk of crashes. The controlled variables vary widely

Table 1. Characteristics of the selected review studies.

	Author/year					
	Liu et al. (2008)	MacLeod et al. (2010)	Byrnes and Gerberich (2012)	Kardamanidis et al. (2010)	Bellefleur and Gagnon (2011)	Horberry et al. (2008)
Objectives	Evaluate the effectiveness of the use of helmets	Evaluate the effectiveness of the use of helmets	Evaluate the effectiveness of the use of helmets	Evaluate the effectiveness of training for motorcyclists before and after acquiring a license	Evaluate the effectiveness of traffic calming interventions in urban areas	Investigate fatigue as a causal factor in motorcycle accidents and explore possible preventive measures
AMSTAR score	10	4	3	10	5	3
Search period	Up to April 2007	Up to 2009	Most recent reference from 2010	Up to September 2008	Up to October 2010	Not indicated, last reference from 2006
Number and type of selected studies	61 studies, all observational (analytical cross-sectional, case-control, and cohorts)	45 studies, all observational (analytical, cross-sectional, case-control, cohorts, before-and-after)	29 studies; designs range from cross-sectional to time series studies on periods from 15 to 20 years	23 studies; 3 randomized trials, 2 nonrandomized trials, 14 cohort, and 4 case-control	Only two report results referring specifically to motorcycles; both time series	Only four specific to motorcycles: a survey, two studies with driver tests, and one narrative review
Participants	Wide spectrum	Wide spectrum	Wide spectrum; only from the United States	Wide spectrum	Urban context excludes studies in rural environment	Wide spectrum
Interventions	Use of helmets compared to nonuse; full-face versus partial coverage helmets	Use versus nonuse of helmets. Promulgation or repeal of a universal helmet law	Universal or partial law (selective) versus absence of law; repeal of an existing law	Compulsory or no training before obtaining a license; noncompulsory training for motorcyclists with or without license	Intervention with several traffic calming measures and establishment of 20 mph speed zones; both were applied to large areas	Training programs, energy drinks, pauses for rest, environmental stimulation, engineering measures
Measures of outcomes	Mortality, facial and cervical injuries, craniocerebral trauma (CCT)	Mortality, mortality from CCT, prevalence of CCT, and critical CCT	Mortality and nonfatal injuries	Fines, accidents, injuries, and death	Accidents, injuries, and death	Not explicitly indicated
Results	Protective effect of helmets. Studies very homogeneous in all the outcomes. Deaths, CCT, and facial injuries significantly decline (RR of around 0.4–0.5). Both helmets with total and partial coverage protect against the risk of CCT,	Supports the effectiveness of helmets and helmet use law (reductions of risk of around 50% or more). Regarding the laws, the six studies conducted outside the United States (in Asia and Europe) show relative reductions in the incidence of CCT	On average, states with universal laws have 22%–33% lower mortality from motorcycle accidents. Partial laws are associated with reductions of 7%–10%. Repeal was associated with an increase in mortality of 12%–23%.	*Compulsory pre-license training*: one study found a reduction in accidents of 15% *Non-compulsory pre-license training*: one study found lower frequency of injuries in one year *Non-compulsory training*: heterogeneous	One study did not find changes in the frequency of accidents. 20 mph speed zones were associated with a reduction in accidents of 37.5% (CI 95%: –31.6 to –43.4).	No direct evidence was found

(*continued*)

Table 1. (*Continued*)

	Author/year					
	Liu et al. (2008)	MacLeod et al. (2010)	Byrnes and Gerberich (2012)	Kardamanidis et al. (2010)	Bellefleur and Gagnon (2011)	Horberry et al. (2008)
	but the superiority of the total-coverage helmets was not demonstrated.	of 20%–40%, and in mortality of 14%–30%.		but predominantly negative results		
	Author/year					
	Novoa et al. (2009)	**Errington et al. (2006)**	**Ameratunga et al. (2006)**	**Morrison et al. (2003)**	**Daniello et al. (2009)**	
Objectives	Summarize the evidence on the effectiveness of road safety interventions	Identify systematic reviews of public health measures to prevent injuries from accidents among young people	Identify evidence on prevention of injury from traffic accidents for vulnerable users in low- and middle-income countries	Review the effectiveness of transportation interventions in order to improve the health of the population	Evaluate the effectiveness of training for motorcyclists; licensing systems	
AMSTAR score	3	7	3	8	3	
Search period	February 2009	September 2004	March 2006	January 2001	Last selected study from 2007	
Number and type of selected studies	Identifies only one study on motorcycles (the systematic review by Cochrane of Liu)	Two reviews on prevention of accidental injuries among young people	Based primarily on previous review (2004) by WHO (updated to 2006), that does not have an explicit description of the methods used	Systematic reviews and meta-analysis. Identifies 28, of which only 2 include some information on motorcycles	Seven studies (mostly observational, one quasi- experimental) on courses (there is a broader and more rigorous review by Cochrane); two observational studies on licensing systems	
Participants	Wide spectrum	People from 15 to 24 years old; only developed countries	Groups of vulnerable users (includes motorcyclists)	Wide spectrum	Wide spectrum	
Interventions	Road safety interventions in general	Road safety interventions in general	Restriction on the engine power of motorcycles for young drivers, increase in the age to obtain a license, restriction on nocturnal use, use of daytime running lights, use of helmet	For motorcycles, reviews were found concerning laws on the use of helmets, training for drivers, use of daytime running lights, reflective clothing	Requirements to obtain a license; graduated licensing system	
Outcome measures	Accidents, injuries, and death	Accidental injuries	Nonspecific a priori	Objective measurements of effects on health		

(*continued*)

Table 1. (*Continued*)

	Author/year					
	Liu et al. (2008)	MacLeod et al. (2010)	Byrnes and Gerberich (2012)	Kardamanidis et al. (2010)	Bellefleur and Gagnon (2011)	Horberry et al. (2008)
					Accident rates (by miles traveled, number of motorcyclists)	
Results	Only one review study was identified (already included in Novoa et al. in its original version).	*Repeal of laws on helmet use*: 25%–40% more deaths; five studies (time series or uncontrolled intervention studies) *Complete versus partial helmets*: No analytical studies *Use of daytime running lights, fluorescent jackets*: lower risk has not been demonstrated *Design of the motorcycle:* only rudimentary evidence on anti-lock brakes; protection for legs *Training of drivers:* five cohort or case control studies with mainly negative results	*Restriction on cylinders and engine power of motorcycles for young drivers*: studies include additional measures (it is not possible to understand the effect isolated from the restriction) *Compulsory use of daytime running lights*: no directly reliable epidemiological evidence. *Increase in the age to obtain a license and restriction of night driving by young people:* no direct evidence of its impact on the rate of accidents	*Laws on helmet use*: reduces deaths by around 30%, and repeal increases mortality by 25%–40%. *Reflective clothing*: no eligible studies *Use of daytime running lights*: 'comparative' studies have not shown any effect *Training of drivers*: most studies demonstrate effect; authors do not detail quality of the studies that sustain the conclusions	One study found lower mortality rates per miles traveled (measure of density or exposure to the use of motorcycles) in states with greater restrictions on obtaining a license (e.g., skill test, course, or others). Under the system of graduated licensing in New Zealand, there was a reduction by 22% in hospitalizations among the 15–19 year-old age group, but the study did not adjust for previous trend that already showed a decline.	

Table 2. Characteristics of the selected original research studies.

Author/ year	Context	Design	Interventions	Results	Observations
Espitia-Hardeman et al. (2008)	Cali, Colombia. Analyzes motorcycle deaths between 1993 and 2001 recorded by surveillance system	Interrupted time series analysis. An autoregressive integrated moving average (ARIMA) adjustment model was used, including the serial correlation.	Decrees on the use of helmets for drivers (1996) and passengers (1997); restrictions on motorcycle use during December holidays (1998); use of reflective vest 24 hours a day courses for violators (2001)	Average reduction in adjusted model of 3.8 deaths/month (CI 95%: 6.5, 1.1; $p < 0.01$) with the compulsory use of helmet for drivers. The use of helmets for passengers was associated with a reduction of 3.3 deaths/month (CI 95%: 5.9, 0.8; $p = 0.01$).	Study without control group or adjustment of physical environment variables (improvements to roads, signalling, illumination, and demarcation)
Cunha & Gonçalves (2001)	Belo Horizonte, Brazil. Analyses 576 victims of accidents treated at the João XXIII Hospital	Descriptive study, but includes an uncontrolled before-and-after measurement	New law with greater penalties for infractions (e.g., not using helmet or lights), more functions to suspend licenses and criminal sanctions for violations	A smaller number of admissions observed after introduction of the law; no differences in the statistics on deaths (only 14 cases in total)	Uncontrolled study. Measurements encompassed a very brief period (three months) close to when the law was changed
French et al. (2009)	Annual data from all the continental U.S. states during the period from 1990–2005	Longitudinal study with adjustment of multiple socio-demographic and traffic variables	Policies on alcohol: revocation of license, zero tolerance for <21 years, BAC limit of 0.08 g/dL. On traffic: speed limits, universal helmet law, compulsory education for motorcyclists	Universal helmet law is the only public policy that significantly influences the numbers of motorcycle deaths. No other policy is significantly associated with mortality rates. Revocation of licenses is moderately positive, but the effect is on nonfatal injuries.	Study attempts to adjust the maximum of confounding factors. It includes sensitivity analysis that controls other secondary variables, such as taxes on alcohol.
Yu et al. (2011)	Hospital in Taichung (China) that treats 50% of the city's trauma cases	Case-control study. Cases: injured with skull and facial injuries; Controls: with other injuries, matched with the time of the accident. Adjusted by age, license, history of infractions, speed, alcohol consumption, severity of the accident	Evaluates three types of motorcycle helmets: -Complete coverage -Face uncovered -Partial coverage Also analyses: -Use versus nonuse of helmet -Fit of the helmet (good or poor) -Other conditions regarding the adequate use of the device	The adjusted odds ratio (OR) for craniofacial injury in those not wearing helmets was 4.54 (CI 95%: 1.25–16.5) and for CCT was 10.4 (CI 95%: 1.82–59.2). Helmet with partial coverage: twice greater risk of CCT than those with complete helmet (OR 2.57 and 2.10, respectively, $p < 0.05$). Compared those wearing the helmet firmly and those without such a firm fitting, which had a greater risk of these injuries (OR 1.94 and 2.50, both statistically significant)	Good-quality study, although subject to potential selection biases and the measurement biases of its own design (the authors themselves suggest that a cohort study be carried out to confirm the findings)
Villaveces et al. (2003)	All U.S. states during the period from 1980–1997	Longitudinal study of annual mortality from motorcycle accidents	(1) Limit of BAC of 0.08 g/dL versus another upper limit (2) BAC of 0.02 g/dL or < in	Adjusted relative risk (RR) of mortality with laws: BAC 0.08 g/dL RR = 0.87 (CI	Good-quality longitudinal study.

(*continued*)

Table 2. (*Continued*)

Author/ year	Context	Design	Interventions	Results	Observations
		and their association with laws on helmets and alcohol. Adjustment of related laws and trends	people under 21 (zero tolerance) (3) Administrative revocation of license (4) Permit driver sobriety checkpoints (5) Prison for repeat offenders	95%: 0.79–0.95) Zero tolerance = Nonsignificant Revocation of license: RR = 0.95 (CI 95%: 0.92-0.98) Prison for repeat offenders: RR = 0.93 (0.89, 0.96). Sobriety controls: Nonsignificant Universal helmet use: RR = 0.67 (CI 95%: 0.63–0.71). Selective helmet use Nonsignificant	The observed effects were modest, in general.
Pérez et al. (2009)	Barcelona, Spain; two periods of three years, before (2002–2004) and after (2004–2008) the new law	Interrupted time series; rates adjusted to the number of registered vehicles and trends	New law that provides an exemption from obtaining a special license to drive lightweight motorcycles (125 cc or less) if the driver has had a license to drive a car for at least three years.	No difference found in the number of injured on light motorcycles, RR 1.03 (CI 95%: 0.80–1.34), or on those with more cylinders, RR 1.08 (CI 95%: 0.98–1.12).	Does not include nonintervention control group.
Novoa et al. (2011)	National-scale study in Spain, data from 2000–2009 period	Interrupted time series; adjusts for trends, a point system for penalties (2006), and for exposure to traffic	Reform in 2007 introduced greater penalties and criminalized behaviours linked to alcohol consumption, speeding, and others.	Among men, all categories (age, urban/rural, motorcycles/ minibikes) showed statistically significant results, with RR between 0.70 and 0.86. The estimated reduction in the rate of injuries is around 20%.	Does not include nonintervention control group.
de Rome et al. (2011)	Australia; subjects between 17–70 years old, or passengers involved in accidents	Analytical cross-sectional study; adjusted for age, sex, type of motorcycle, accident (single or multiple-vehicle), impact, and speed	Protective clothing (excludes those designed only for the climate), with or without protective armor	Jackets for motorcyclists, RR hospitalization = 0.79, trousers RR = 0.49, gloves RR = 0.41 (all results insignificant). Protective armor adjusted to the body: injuries to torso RR = 0.77, hands and wrists RR = 0.55, legs RR = 0.60. Nonspecific boots for motorcycles: RR = 0.46 of injury versus shoes or sandals.	Sensitivity analysis including only hospitalized subjects showed results similar to the global ones.
Teoh (2010)	National Registry of Vehicles and Fatality Analysis Reporting System (FARS), the United States, 2003–2008 period	Analytical cross-sectional study; 430,000 motorcycles without anti-lock brake systems (ABS) and 115,000 with ABS. Compared only similar models with and without ABS.	Anti-lock brake systems	The rate of fatal accidents per 10,000 registered vehicles was 4.1 for motorcycles with ABS and 6.4 for those without ABS. RR = 0.625 (CI 95%: 0.425–0.912).	Adjustment was not made. Drivers without ABS had more infractions for speeding or alcohol, but greater frequency of use of helmet, which means that there is no clear bias in a specific direction.

Table 3. Methodological quality of the selected review studies.

Study	AMSTAR[a]	Observations
Kardamanidis et al. (2010)	10	High-quality review. Authors analyse the validity of the selected studies in detail.
Bellefleur and Gagnon (2011)	5	Review limited to the last decade. Articles in English or French; only about developed countries. Narrative summary provides grouped results obtained from previous meta-analyses.
Horberry et al. (2008)	3	Review limited to articles about developed countries. Does not explicitly explain methods of analysis of the studies. Subject scarcely studied.
Novoa et al. (2009)	3	Systematic examination of review studies. Limited to published studies. Does not include critical analysis of the selected reviews.
Errington et al. (2006)	7	Systematic examination of review studies. Limited to articles in English about developed countries. Narrative summary provides grouped results obtained from previous meta-analyses.
Ameratunga et al. (2006)	3	Broad search, including grey literature. Little explanation of the selection criteria of the studies. Does not include critical analysis of the selected studies.
Liu et al. (2008)	10	High-quality review. Includes only observational studies.
MacLeod et al. (2010)	4	Search limited to MEDLINE. All observational studies. Narrative summary, without grouped results.
Byrnes and Gerberich (2012)	3	Search limited to MEDLINE. Only studies in the United States published in English. Narrative summary, without grouped results.
Morrison et al. (2003)	8	Review of systematic reviews.
Daniello et al. (2009)	3	Review has little explanation of its methods. Does not include clear description of the design of the selected studies.

[a]Scale of score from 0 to 11.

between studies. In general, the data and measurements are obtained from standardized sources.

The preventive measures analysed in these studies include: laws on helmet use, different types of helmets, transit restrictions, reflective vests, courses for violators, greater penalties for infractions, administrative revocation of licenses, zero tolerance of alcohol, a blood alcohol concentration (BAC) limit of 0.08 g/dL, speed limits, compulsory education, driver sobriety checkpoints, protective clothes, and anti-lock brakes.

Summary of evidence

Table 5 summarizes the principal findings, including the approximate magnitude of the effects of interventions that have shown statistically significant results. The types of studies used to evaluate measures and sources of the studies selected are included in the table.

Protective devices

Helmets

The most frequently studied preventive measure is the use of helmets. Dozens of observational studies compiled through systematic reviews (Liu et al., 2008; MacLeod et al., 2010) have demonstrated that using a helmet reduces the risk of death, craniocerebral trauma (CCT), and facial injuries by up to one half. There is great homogeneity in the direction and magnitude of the association among the studies and in all the evaluated outcomes, even when comparing adjusted and unadjusted studies.

With regard to the type of helmet (total coverage vs. partial coverage), several analytical observational studies (Liu et al., 2008) suggest that both types of helmets have a protective effect against the risk of CCT. The selected systematic reviews found three studies with no significant results in terms of comparing the types of helmets. Yu et al. (2011) report on a recent case-control study that found that those who used partial-coverage helmets have twice the risk of encephalic cranial injury (odds ratio (OR) = 2.57; confidence interval (CI) 95%: 1.50–4.40) or cerebral injury (OR = 2.10; CI 95%: 1.01–4.38) compared to those who used a helmet providing total coverage.

Legislation in several countries regarding the use of helmets was evaluated. MacLeod et al. (2010) compiled a review of 20 before–after studies and two comparisons of mortality in states of the United States with and without helmet use laws. Their review includes six studies conducted in Asia and Europe (Chiu, Kuo, Hung, & Chen, 2000; Ferrando, Plasencia, Orós, Borrell, & Kraus, 2000; Ichikawa, Chadbunchachai, & Marui, 2003; Servadei et al., 2003; Panichaphongse, Watanakajorn, & Kasantikul, 1995; Tsai & Hemenway, 1999). The studies show consistent, statistically significant reductions of between 20% and 40% in the incidence of CCT and in mortality (RR

Table 4. Methodological quality of original research studies.

Interrupted time series and uncontrolled before-and-after studies						
Criteria	Cunha and Gonçalves (2001)	Espitia-Hardeman et al. (2008)	French et al. 2009)[a]	Villaveces et al. (2003)[a]	Pérez et al. (2009)	Novoa et al. (2011)
1. The intervention is independent of other changes in time	NC[b]	NC	NC	NC	NC	NC
2. The data were analysed appropriately[c]	No	Yes	No	Yes	Yes	Yes
3. Bases the number of measurements on pre- and post-intervention	No	No	No	No	No	No
4. Gives an explanation of the type of effect of the intervention	No	Yes	Yes	Yes	Yes	Yes
5. Sources and methods used for data collection were the same before and after the intervention	Yes	Yes	Yes	Yes	Yes	Yes
6. Blind measurement of primary outcomes or measurement through objective criteria	No	Yes	Yes	Yes	Yes	Yes
7. Integrity of the data set: covers 80% or more of the projected subjects or measurements	NC	NC	Yes	NC	NC	NC
8. Primary outcome measures reliable[d]	NC	Yes	Yes	Yes	Yes	Yes

Case and control studies/analytical cross-sectional studies			
Criteria	Yu et al. (2011)	de Rome et al. (2011)	Teoh (2010)
1. Addresses a clearly defined research question	Yes	Yes	Yes
2. Cases recruited in an acceptable manner[e]	Yes	NC	Yes
3. Controls selected through a method sufficient to avoid selection biases[f]	Yes	No	Yes
4. Exposition measured adequately to minimize the risk of bias[g]	Yes	NC	Yes
5. Adjustment was made in the design of or during the analysis to relevant confounding variables.	Yes	Yes	No

[a]Study does not correspond to interrupted time series as such, but to analytical longitudinal study with data added to population scale.
[b]NC: Not clear/cannot be confirmed.
[c]ARIMA models or time-series regression for the data analysis; adjustment/evaluation of the serial correlation.
[d]For example, with agreement between observers ≥ 90% or Kappa ≥ 0.8, or measured through automated system, or through a standardized test or instrument.
[e]Case definition, reference population, incidence/prevalence.
[f]Represents the same control population, matching sample population or random.
[g]Definition, validity, objectivity of the measurements; similar methods among the groups, blind when feasible, correct temporal relation.

between 0.5 and 0.8) where helmet-use laws exist. In an interrupted time series study in Cali, Colombia (Espitia-Hardeman et al., 2008), the authors found an average reduction of four deaths/month (CI 95%: 6.5–1.1; $p < 0.01$) as a result of the law that introduced compulsory use of helmets for drivers, and an average reduction of three deaths/month (CI 95%: 5.9–0.8; $p = 0.01$) as a result of the law requiring passengers to use helmets.

Table 5. Summary of results.

Intervention	Principal studies[a]	Outcomes evaluated	Result (approximate magnitude of the effect)	Reference
Use of helmet	Analytical observational studies	Mortality, craniocerebral trauma (CCT), and facial injuries	Helmet reduces risk by half or more (relative risk [RR] approximately 0.5)	Liu et al. (2008), MacLeod et al. (2010)
Type of helmet: total versus partial protection	Analytical observational studies	CCT	Both helmet types reduce the risk of CCT. Three original research studies do not show significant differences between one helmet and the other, but a case and control study found a RR = 2–2.5 of craniocerebral injury with partial helmets	Liu et al. (2008), Yu et al. (2011)
Laws on helmet use	Before-and-after and cross-sectional analytical studies (states with or without law)	Mortality, CCT	Relative reductions in the incidence of CCT of between 20% and 40%. Mortality: RR between 0.5 and 0.8; 30% less with universal laws versus the absence of law. Repeal of law increases mortality and nonfatal injuries by 10%–20%	MacLeod et al. (2010)
Helmet laws: universal versus selective	Cross-sectional analytical studies	Mortality, nonfatal injuries	Partial or selective laws: effect is three times less than with the universal law	Byrnes and Gerberich (2012)
Protective clothing	Cross-sectional analytical study	Hospitalization, injury of lower limbs	Lower risk of hospitalization with use of jackets, trousers, or gloves (RR = 0.4–0.9). Lower risk of injury to limbs with use of boots (RR = 0.5)	de Rome et al. (2011)
Airbags	None	N/A[b]	N/A	Errington et al. (2006)
Protections for the legs	None	N/A	N/A	Errington et al. (2006)
Anti-lock brakes	Cross-sectional analytical study	Rate of fatal accidents	RR = 0.6 for fatal accidents in models with anti-lock brakes.	Teoh (2010)
Restrictions on cylinders and engine power for young drivers	None	N/A	N/A	Ameratunga et al. (2006)
Compulsory training before obtaining license	Randomized trials	Frequency of accidents	One case- control study found a 14%, 21%, and 13% reduction for 6, 12, and 24 months of training, respectively; another case-control study yielded inconclusive results.	Kardamanidis et al. (2010)
Noncompulsory training to obtain a license	Randomized trials	Mortality, injuries	Injuries at one year: RR = 0.6 Injuries at two years: nonsignificant Mortality: nonsignificant	Kardamanidis et al. (2010)
Noncompulsory training	Analytical observational studies	Accidents	Inconclusive results or results showing greater rates of accidents in the intervened groups predominate	Kardamanidis et al. (2010)
Greater restrictions on the acquisition of a license	Ecological study	Mortality	Lower rates per miles travelled in states that require skills test or include three or more restrictions (RR = 0.8) Lower rates per number of	Daniello et al. (2009)

(*continued*)

Table 5. (*Continued*)

Intervention	Principal studies[a]	Outcomes evaluated	Result (approximate magnitude of the effect)	Reference
			drivers in states that require courses (RR = 0.8)	
Graduated licensing system	Interrupted time series	Hospitalizations	20% reduction in 15–19 year-old group (study with potential for high bias), but not in 20–24 year-old or ≥ 25 year-old groups	Daniello et al. (2009)
Exemption from light motorcycle license for those who have an automobile license	Interrupted time series	Injuries	No observed effect	Pérez et al. (2009)
0.08 g/dL blood alcohol concentration	Longitudinal studies	Mortality	RR = 0.9	French et al. (2009), Villaveces et al. (2003
Zero tolerance for alcohol (0.00 g/dL for those < 21 years)	Longitudinal studies	Mortality	No observed effect	French et al. (2009), Villaveces et al. (2003)
Administrative revocation of license for alcohol	Longitudinal studies	Mortality	RR = 0.95	French et al. (2009), Villaveces et al. (2003)
Laws that permit driver sobriety checkpoints	Longitudinal studies	Mortality	No observed effect	Villaveces et al. (2003)
Measures against fatigue	None	N/A	N/A	Horberry et al. (2008)
Physical traffic calming interventions (urban)[c]	Time series	Accidents	No observed effect	Bellefleur and Gagnon (2011), Cloke et al. (1999)
Traffic calming (urban) zones of 32 km/h (20 mph)	Time-controlled series	Accidents with injuries, fatal accidents, or with severe injuries	Total accidents with injuries: 30% reduction Accidents with death or severe injuries: 40% reduction	Bellefleur and Gagnon (2011), Grundy et al. (2009)
Use of daytime running lights	Time series	Accidents, injuries	No observed effect	Errington et al. (2006), Morrison et al. (2003)
Reflective clothes	None	N/A	N/A	Errington et al. (2006), Morrison et al. (2003)
Greater penalties for alcohol consumption, speeding	Interrupted time series, longitudinal study	Accidents	Accident risk RR = 0.8 Risk of fatal injuries RR = 0.9	Novoa et al. (2011), Villaveces et al. (2003)

[a]Only of the eligible types.
[b]N/A = not available.
[c]Intersections and crossings with large numbers of pedestrians, reductions in speed, traffic circles, elevated median strips, extensions of sidewalks, and others.

In another review, mainly of cross-sectional studies in the United States, Byrnes and Gerberich (2012) compare different types of laws – universal, partial, or selective – with special requirements for some drivers. Of those studies, 95% ($n = 55$ studies) show mortality from motorcycle crashes is 30% lower with universal laws than with the absence of such laws. With partial laws, the effectiveness holds in the driver subgroup from 15–20 years old, but the global effect is three times less than with the universal law. In turn, the repeal of these laws was associated with an increase of between 12% and 23% in mortality, compared with states that retained the laws. The results are similar with regard to nonfatal injuries.

Protective clothing

The limited evidence available suggests a protective effect against injuries to vulnerable body parts and lower risk of hospitalization when protective clothing is worn. De Rome et al.(2011) identified a cross-sectional analytical

study in Australia, adjusted by type of motorcycle, crash, and estimated speed of impact. The study found lower risks of hospitalization among motorcyclists wearing jackets (RR = 0.79; CI 95%: 0.69–0.91), trousers (RR = 0.49; CI 95%: 0.25–0.94), or gloves (RR = 0.41; CI95%: 0.26–0.66). Boots nonspecific to motorcycles were also associated with a lower risk of injury to lower limbs, compared with shoes or sandals (RR = 0.46; CI 95%: 0.28–0.75).

Protective devices for motorcycles

Errington et al. (2006) mentions that only rudimentary evidence has been reported on potential measures, like airbags and leg protection. Additional studies on this topic were not identified.

Mechanical properties of the motorcycle

Anti-lock brakes

Only one study on the use of anti-lock brakes was identified. Teoh (2010) carried out cross-sectional analysis on 430,000 motorcycles without antilock brake system (ABS) and 115,000 equal models with ABS. The rate of fatal crashes was 4.1 per 10,000 registered vehicles for motorcycles with ABS, and 6.4 for those unequipped with the system (RR = 0.625; CI 95%: 0.43, 0.91). The study did not use any adjustment mechanism, meaning that the effect of these devices on crashes and their consequences in the urban context is difficult to establish.

Restriction of cylinder capacity and engine power of motorcycles for young drivers

The review by Ameratunga et al. (2006) discusses the evaluation of a transportation law in 1981 in the United Kingdom that included several measures directed toward preventing motorcycle crashes, including a reduction in the engine power of motorcycles driven by apprentice drivers. Since the law also included greater requirements to obtain licenses, which resulted in a significant decline in such licenses, it is not possible to isolate the effect of the reduction of cylinder capacity.

Skills and physical condition of the driver

Training

The Cochrane review by Kardamanidis et al. (2010) identifies 3 randomized controlled trials, 2 nonrandomized trials, and 18 analytical observational studies (cohorts, case-control). Most of the nonrandomized studies had a potential for significant selection bias because the participants were on average younger, included more females, and were less experienced, while the control group was recruited from the general population of motorcyclists and participants were predominantly male, older, and experienced. In general, the studies omitted the adjustment of relevant control variables. Different types of theoretical, practical courses were evaluated, from 2 to 24 hours over one to three days, to the absence of formal training. The studies evaluated the impact of:

> *Compulsory training before licensing (five studies; two were randomized controlled trials)*: Only one of the randomized studies found a modest effect on the frequency of crashes (14%, 21%, and 13% reductions for 6, 12, and 24 months, respectively; $p < 0.05$); all the remaining studies had inconclusive results.
>
> *Non-mandatory pre-license training (three studies; one was a randomized controlled trial)*: A cluster randomized trial found a lower frequency of injuries over one year but not over two years (10.5/1000 inhabitants; CI 95%: 9.2–12.0 versus 16.9/1000 inhabitants; CI 95%: 15.2–18.5), and there was no difference in mortality.
>
> *Non-compulsory training (12 studies, all observational)*: Two quasi-experimental studies did not show a reduction in the crash rate, and the only case-control study did not show a significant difference. The multiple cohorts analysed show heterogeneous results, but those with higher crash rates in the intervened groups predominate.

It can be concluded from this evidence that strategies based on the formal education of drivers do not seem to be effective in improving safety in the use of motorcycles.

Interventions related to licensing

Daniello et al. (2009) cite one study in the United States that observed lower mortality per miles travelled (measure of density of exposure) in states with greater restrictions on obtaining a license. The review cites another study that evaluated a system of graduated licensing introduced in 1987 in New Zealand that showed a 22% reduction in hospitalizations. The latter study was not adjusted to control for previous trends that already showed a decline, which means that the result is not directly attributable to the intervention. The results are also explained by the lower rate of license acquisition among young people and the consequent reduced exposure to crashes.

In another study, Pérez et al. (2009) used an interrupted times series in Spain to evaluate the effect of a law that exempted the license requirement to drive light motorcycles (125 cc or less) for persons who had been licensed to drive a car for at least three years. Once the results were adjusted per number of registered vehicles, the difference was not significant for the number of injuries on light motorcycles (RR = 1.03; CI 95%: 0.80–1.34)

or for larger capacity engines (RR = 1.08; CI 95%: 0.98–1.12).

Measures related to driving under the influence of alcohol

French et al. (2009) evaluated three policies on alcohol: administrative revocation of a license (e.g., for those who refuse to take a blood alcohol test), zero tolerance of alcohol (BAC of 0.00 g/dL for people under 21), and a BAC limit of 0.08 g/dL. The authors did not find an association between these policies and mortality from motorcycle crashes. Villaveces et al. (2003) found lower mortality in motorcyclists when there are laws that limit BAC to 0.08 g/dL (RR adjusted 0.87; CI 95%: 0.79–0.95) and laws for the administrative revocation of a license (RR adjusted 0.95; CI 95%: 0.92–0.98), but not where there are zero tolerance laws or laws that permit driver sobriety checkpoints. Since the French et al. (2009) study includes a more exhaustive adjustment of potential confounding variables, it is doubtful that these measures have significant effects on crash and injury rates. Nevertheless, since the results refer only to the United States, their applicability in other contexts is uncertain.

Measures to protect against fatigue in motorcyclists

No studies were identified that fulfilled the inclusion criteria.

Traffic calming interventions

A recent systematic review (Bellefleur & Gagnon, 2011) includes two studies that report results specifically on motorcycles. One of them is a time series study of a program in a broad area of London (Cloke et al., 1999) that included several traffic calming measures. The study did not find changes in the annual frequency of motorcycle crashes after the interventions. The other (Grundy et al., 2009) is an interrupted time series study that evaluates the impact of 399 urban areas with 20 mph (32 km/h) speed limits installed gradually in London beginning in 1990. The adjusted results showed reductions of 32.6% and 39.1% in the total number of motorcycle crashes with injuries and death, respectively, without evidence of a migration phenomenon (increase of crashes in areas adjacent to the intervened areas). A third study (French et al., 2009) evaluates the establishment of maximum speed limits and did not find a protective effect, at state level. The evidence from the Grundy et al. (2009) study indicates that traffic calming interventions of low speed zones in urban areas can help reduce motorcycle crashes.

Interventions to improve the visibility of the driver or the vehicle

Although interventions such as daytime running lights and reflective clothing can help other drivers see motorcyclists better, there is no empirical evidence that this results in a lower risk of crashes or injuries (Errington et al., 2006; Morrison et al., 2003). Time series studies in the United States have not demonstrated that the use of daytime running lights has any effect on crash rates in states where their use is compulsory.

Strengthening penalties

Novoa et al. (2011) conducted a national-scale, interrupted time series study in Spain with data from 2000 to 2009, adjusted for multiple covariables. The study evaluates a reform of the penal code in 2007 that introduced greater penalties and criminalized various behaviours related to alcohol consumption and speeding. The results associated the reform with a significant reduction in the risk of crashes in urban areas (RR = 0.83; CI 95%: 0.77–0.90) and rural areas (RR = 0.71; CI 95%: 0.64–0.78). Villaveces et al. (2003) found that the existence of laws that require jail time for repeat offenders under the influence of alcohol was associated with a slightly lower risk of fatal injuries (RR = 0.93; CI 95%: 0.89–0.96). Thus, there is limited but consistent evidence that imposing such legal sanctions can reduce risk.

Conclusions

This report presents an up-to-date summary of the evidence on the effectiveness of various measures to prevent motorcycle crashes and their consequences. The authors believe they have not omitted any relevant preventive measures that have been evaluated through acceptable research design for their effect on health or the frequency of crashes. These objective data can be used as a reference by transit experts and decision-makers for the development of specific legal, regulatory, or community-level recommendations.

Most of the research comes from developed countries and thus it is important to consider the recommendations in the context of local conditions in countries. In areas with little regulation or with limited adherence to measures of proven effectiveness, such as the use of helmets, efforts should be directed primarily at expanding such practices, while in other areas, more innovative forms of intervention can be examined.

The studies on this topic are mainly of analytical observational design, with the limitations that this implies. The only interventions evaluated through randomized trials were the requirement for compulsory training before obtaining a license and non-mandatory pre-license training. In both cases, the studies showed mild to moderate reductions in the frequency of crashes and injuries as a result of the intervention.

Another group of preventive measures has been evaluated mainly through cohort, case-control, and cross-

sectional analytical studies. Most of the studies with positive results (for example, a statistically significant RR = 0.5) are of these types, and refer to interventions that can be evaluated on an individual scale. Examples are the use of helmets, protective clothing, and anti-lock brakes. There were no significant findings regarding non-compulsory training. These evaluations have the potential for selection bias because they refer to personal choices by the driver.

The measures introduced through laws have been evaluated using before–after, interrupted time series, and longitudinal studies that compare the measures scaled to population before and after the law was in effect. Most of the interventions of this type show no or low-level results (≤10%). Among the measures without any demonstrated effect are laws on zero tolerance for alcohol (BAC 0.00 g/dL for people under age 21), laws that permit police to conduct driver sobriety checkpoints, laws that require the use of daytime running lights, and traffic calming interventions on urban road networks. However, the establishment of low-speed zones in urban areas could be effective in some contexts.

Some potential effect, although of low magnitude, is seen with other laws directed toward alcohol consumption and the strengthening of sanctions: a BAC level of 0.08 g/dL, administrative revocation of licenses (e.g., from those who refuse to take a blood alcohol test), and more severe penalties for driving under the influence of alcohol or speeding.

In an ecological study, greater restrictions on obtaining a license have been associated with lower mortality (RR = 0.8). Since obtaining a license is a voluntary act, and the regulations (laws) are also influenced by the context, these studies have high potential for bias.

Regarding the use of a graduated licensing system, an interrupted time series study found a positive result in one of three subgroups (15–19 year olds). This finding in a single study may reflect a true association, but also could be a random finding.

Finally, this review did not identify eligible studies that found evidence of the effectiveness of restrictions on engine power of motorcycles for young drivers, protective devices for the legs, reflective clothing, or measures directed to combat fatigue of motorcyclists.

In short, the measures analysed could be classified as follows:

Effective measures:

- Compulsory training before obtaining a license
- Non-mandatory pre-license training
- Use of helmets
- Use of protective clothing
- Use of anti-lock brakes

Potentially effective measures:

- Low-speed zones in urban areas
- Blood alcohol concentration limit of 0.08 g/dL
- Administrative revocation of license (e.g., for refusing to take a blood alcohol test)
- Greater penalties for driving under the influence of alcohol
- Greater penalties for speeding
- Skill test requirement to obtain a license
- More restrictions on obtaining a license

Ineffective measures:

- Zero tolerance alcohol laws (0.00 g/dL for people under 21 years old)
- Use of daytime running lights
- Traffic calming interventions to the urban road network
- Non-compulsory training

Measures not well evaluated:

- Graduated licensing
- Allowing driver sobriety checkpoints
- Restriction on engine power on motorcycles used by young drivers
- Protective devices for the legs
- Reflective clothing
- Measures to combat fatigue

Disclosure statement

The authors are staff members of the Pan American Health Organization and are themselves responsible for the views expressed in the Article, which do not necessarily represent the views, decisions or policies of the Pan American Health Organization.

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