Graduated driver licensing for reducing motor vehicle crashes among young drivers (Review)

Russell KF, Vandermeer B, Hartling L

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[Intervention Review]

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Kelly F Russell[1], Ben Vandermeer[2], Lisa Hartling[1]

[1]Department of Pediatrics, University of Alberta, Edmonton, Canada. [2]Department of Pediatrics, Alberta Research Centre for Child Health Evidence & University of Alberta Evidence-based Practice Centre, Edmonton, Canada

Contact address: Lisa Hartling, Department of Pediatrics, University of Alberta, Aberhart Centre One, Room 9424, 11402 University Avenue, Edmonton, Alberta, T6G 2J3, Canada. hartling@ualberta.ca. lisa.hartling@ualberta.ca.

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ABSTRACT

Background

Graduated driver licensing (GDL) has been proposed as a means of reducing crash rates among novice drivers by gradually introducing them to higher risk driving situations.

Objectives

To examine the effectiveness of GDL in reducing crash rates among young drivers.

Search methods

Studies were identified through searching MEDLINE, EMBASE, CINAHL, Healthstar, Web of Science, NTIS Bibliographic Database, TRIS Online, SIGLE, the World Wide Web, conference proceedings, consultation with experts and reference lists in relevant published literature. The searches were conducted from the time of inception to May 2009, and the Cochrane Injuries Group conducted an updated search of the TRANSPORT database in September 2009.

Selection criteria

Studies were included if: 1) they compared outcomes pre- and post-implementation of a GDL program within the same jurisdiction, 2) comparisons were made between jurisdictions with and without GDL, or 3) both. Studies had to report at least one objective, quantified outcome.

Data collection and analysis

Results were not pooled due to substantial heterogeneity. Percentage change was calculated for each year after the intervention, using one year prior to the intervention as baseline. Results were adjusted by internal controls. Analyses were stratified by denominators (population, licensed drivers). Results were calculated for the different crash types and presented for 16 year-olds alone as well as all teenage drivers.

Main results

We included 34 studies evaluating 21 GDL programs and 2 analyses of >40 US states. GDL programs were implemented in the US (n=16), Canada (n=3), New Zealand (n=1), and Australia (n=1) and varied in their restrictions during the intermediate stage. Based on the Insurance Institute for Highway Safety (IIHS) classification, eleven programs were good, four were fair, five were marginal, one was poor and two could not be assessed. Reductions in crash rates were seen in all jurisdictions and for all crash types. Among 16 year-old drivers, the median decrease in per population adjusted overall crash rates during the first year was 15.5% (range -27 to -8%, five studies). There was a decrease in per population adjusted injury crash rates (median -21%, range -46 to -2%, five studies). Results for all teenage drivers, rates per licensed driver, and rates adjusting for internal controls were generally reduced when comparing within jurisdictions.

Authors' conclusions

GDL is effective in reducing crash rates among young drivers, although the magnitude of the effect varies. The conclusions are supported by consistent findings, temporal relationship, and plausibility of the association. Stronger GDL programs (i.e. more restrictions or higher quality based on IIHS classification) appear to result in greater fatality reduction. Future studies should focus on which components and combination of components yield the greatest reductions.

PLAIN LANGUAGE SUMMARY

Graduated driver licensing for reducing motor vehicle crashes among young drivers

Young drivers are at high risk of involvement in motor vehicle crashes. Graduated driver licensing (GDL) has been proposed as a means of reducing crash rates among novice drivers by gradually introducing them to higher risk driving situations. This review found 34 studies that have evaluated various types of GDL programs. All of the studies reported positive findings, with reductions for all types of crashes among all teenage drivers. However, the size of the reductions varied and, based on the included studies it is not possible to say which aspects of GDL programs have the biggest effect. Future research on GDL should evaluate the relative impact of different program components.

BACKGROUND

It is well recognized that teenagers are more likely to be involved in motor vehicle crashes (MVCs) compared to older drivers (Foss 2000). In Canada and the United States, crash rates per mile driven are three to ten times higher among teenage drivers than among the older, more experienced drivers (Doherty 1998; Foss 2000). MVCs account for 40% of fatalities from all causes among adolescents aged 16 to 19 years (Ferguson 1996). Teenage drivers represent not only a threat to themselves, but to other road users (Foss 1999). While 15-20 year-olds compose 6.3% of the American population, they are responsible for 12.6% of traffic fatalities (NHTSA 2005). A 16 year-old driver's crash rate per mile driven is twice as high as 18-19 year-old drivers and 10 times higher than that of 30-59 year-old drivers (Williams 2003c).

Research suggests that the two most likely factors contributing to this inordinately high risk for crashes among teenage drivers are driving inexperience and immaturity (Foss 1999; Williams 1997). Lack of driving experience contributes to a lower level of skills and inability to respond effectively under less than optimal conditions (e.g. driving at night and having passengers). Lack of developmental maturity among teenagers can lead to impulsive behavior, poor decision making, overconfidence in their abilities, as well as more risky driving styles, such as speeding, following too closely or dangerous passing (Foss 1999; Williams 1997).

Risk factors for MVCs have traditionally been addressed through licensing (Simpson 2003), education, and enforcement (Doherty 1998). Driver licensing systems were imposed to "ensure that novices meet certain minimal requirements deemed necessary to operate a motor vehicle safely in traffic" (Simpson 2003). Probationary and provisional licensing programs were precursors to graduated licensing and, like graduated licensing, sought to address the higher crash rates of young drivers. In a review of the literature on the effectiveness and role of driver education, Mayhew and colleagues concluded that the existing evidence did not show that formally trained drivers had lower crash rates (Mayhew 1998).

In fact, they identified several studies that have shown driver education to be associated with increased crash rates. This could be due to the fact that these programs may place more drivers on the road. Likewise there is no evidence that enforcement on its own mitigates the effects of young driver inexperience on crash rates (Waller 2003).

Description of the intervention

Since the 1970s, graduated driver licensing (GDL) programs have been discussed and implemented as a means of controlling the risks and reducing crash rates among young drivers. The basic premise of GDL is that individuals begin driving under relatively safe conditions that involve lower risk, and are gradually introduced to more complex or higher risk driving situations (Langley 1996; Mayhew 2000; Williams 1999).

The ideal GDL program has three stages (Foss 1999). The beginning stage generally requires that an adult with a valid license be present at all times; under GDL this stage should last for an extended, mandatory amount of time. The intermediate stage allows the new driver to drive alone but with certain restrictions (e.g. no night-time driving, limitations on extra passengers, restrictions on blood alcohol concentration - BAC). The final stage is full licensure, whereby the individual is free to drive independently under the usual laws and regulations.

Various organizations have put forward recommendations for GDL, for example: the Insurance Institute for Highway Safety and the Traffic Injury Research Foundation (Williams 1999), the National Committee on Uniform Traffic Laws and Ordinances (Foss 1999), and Mothers Against Drunk Driving (MADD 2000). Based on these recommendations, the key elements appear to be: delayed full-privilege licensure, extended periods of supervised practice driving, and restrictions during the intermediate stage on night driving, BAC (not applicable to all jurisdictions), and extra passengers. The recommendations for individual components within GDL programs are based on empirical evidence of risk factors for crashes involving young, new drivers.

Though GDL programs were first described in the 1970s, they were slow to be accepted and implemented. The number of jurisdictions in North America with full GDL programs has steadily increased since the early 1990s; all states in the United States except North Dakota, and all Canadian provinces and territories except Nunavut, have a full three-stage GDL (IIHS 2011; Northwest Territories Transportation 2010; Williams 2003b). The widespread implementation of GDL has provided an opportunity to study their overall effectiveness.

Why it is important to do this review

In 1999, Foss published the results of a systematic review of the effectiveness of GDL in reducing MVCs (Foss 1999). This review was critically appraised by the NHS Centre for Reviews and Dissemination (CRD) at the University of York, England. The NHS CRD identified the following shortcomings of the review: authors did not report how decisions on inclusion and exclusion of studies were made, how methodological quality was assessed, or how data extraction was done (Foss 199). No overall estimates of effect were calculated, study results were instead described separately. The authors of the review concluded that there was evidence that a restriction on night-time driving reduced crashes among young drivers. The authors stated that they could not make a definitive conclusion about the overall effectiveness of GDL due to insufficient data. At the time of their review only one program (New Zealand) had been evaluated: this program showed positive results with a 7-8% reduction in the rates of teenage driver injury crashes. The purpose of this review was to update and expand upon the work begun by Foss et al (Foss 1999). We also sought to address the shortcomings identified by the NHS CRD by reporting on criteria and methods for inclusion, quality assessment, and data extraction. This version is an update of the original review published in 2004 (Hartling 2004).

OBJECTIVES

The objective of this review was to examine the effectiveness of graduated driver licensing programs in reducing crash involvement among young drivers.

METHODS

Criteria for considering studies for this review

Types of studies

Due to issues related to logistics and feasibility, the preponderance of research in this area involves studies with an ecological design. Ecological (or aggregate risk) studies are those in which the intervention of interest (i.e. GDL) is applied across an entire population (Hingson 2001). Often there is limited or no information on how vigorously the laws are enforced at an individual level. Ecological studies may take a number of forms, for example: studies involving a single population in which outcomes are measured before and after legislation is implemented (before-and-after or pre-post study); studies that compare two or more populations concurrently; and, studies evaluating both within-population outcomes over time and between-population differences (Hingson 2001).

Studies were included in the review if: 1) they compared outcomes immediately pre and post-implementation of a GDL program; 2)

comparisons were made between similar or adjacent jurisdictions with and without a GDL program; or 3) both.

Types of participants

Studies evaluating populations with GDL were included in the review. The target population of interest was teenage drivers. While some jurisdictions apply GDL to all novice drivers regardless of age (e.g. Ontario, Canada), only data pertaining to teenage drivers were included. Teenage drivers were defined as drivers younger than 20 years of age.

Types of interventions

Studies were considered for inclusion if they evaluated GDL. For the purposes of this review, GDL programs must have a minimum of three stages that allow the new driver to progress from lower to higher risk driving conditions: 1) an initial period limited to supervised driving, 2) an intermediate stage allowing for unsupervised driving under one or more conditions that involve lower risk, and 3) finally unrestricted full licensure (Foss 1999). Lower-risk conditions during the intermediate stage include: night curfews, limited number of passengers, lower BAC, roadway restrictions, or limitations on the number of violations, convictions, crashes, or demerit points. Any licensing program that did not include an intermediate stage was excluded. Judgment regarding the definition of GDL was based on the information provided in the written report.

Types of outcome measures

Studies were included if they reported at least one objective, quantified outcome. Different denominators (i.e. population, number of licensed drivers) were used for rate calculations; this was accounted for in the analysis by stratifying according to the different denominators.

Primary outcomes

The primary outcome of interest was overall crash rates of teenage drivers (i.e. crashes involving fatalities, injuries, and property damage only - PDO).

Secondary outcomes

Secondary outcome measures included:

- rates of injury crashes (crashes resulting in fatal or non-fatal injuries to the driver or passenger(s)),
- hospitalizations (hospital admissions of the driver or passenger(s) due to crashes),
- fatality crashes (crashes involving fatal injuries to the driver or passenger(s)),
- night-time crashes (crashes occurring during curfew hours specific to each jurisdiction),
- alcohol crashes (alcohol involved),
- and traffic violations and the amount of property damage.

Search methods for identification of studies

Searches were not restricted by date, language, or publication status.

Electronic searches

We searched the reference lists of previously published reviews and collated a core list of relevant studies. We searched MEDLINE and EMBASE using the search strategy in Appendix 1 and adapting it when necessary. Initial search results were compared against the core list to ensure that important studies were picked up, and to identify relevant text words and key headings assigned to these studies. Using search strategies designed specifically for each database, we also searched:

- CINAHL (1982 to May 2009),
- Healthstar (1975 to May 2009),
- ISI Web of Science: Science Citation Index Expanded (1970 to May 2009)
- NTIS Bibliographic Database (National Technical Information Service),
- TRIS Online (Transportation Research Information Service),
- SIGLE (1976 to May 2009),
- and the World Wide Web (May 1, 2009):
    - Insurance Institute for Highway Safety-US,
    - National Highway Traffic Safety Administration-US,
    - Traffic Injury Research Foundation (Canada - Young and New Drivers section),
    - Land Transport Safety Authority-NZ,
    - Swedish National Road Administration,
    - Federal Office of Road Safety-Australia,
    - Transport Research Laboratory,
    - National Highway Traffic Safety (Teen Drivers and New Drivers sections),
    - Swedish National Road Administration,
    - Transport Research Laboratory,
    - Federal Office of Road Safety - Australia - now Australian Transport Safety Bureau (Infrastructure Australia, Australian Transport Safety Bureau, Bureau of Infrastructure, and Transport and Regional Economics sections),
    - SafetyLit (includes 3400 current scholar journals from many nations that are hand searched),
    - International Council on Alcohol, Drugs and Traffic Safety conference abstracts,
    - Licensing and Young and Novice Drivers Land Transport Safety Authority - New Zealand.

The Cochrane Injuries Group conducted an updated search of the TRANSPORT database in September 2009: TRANSPORT (Ovid SP) (includes: Transportation Research Information Services (TRIS), International Transport Research Documentation (ITRD), TRANSDOC) (1988 to Sept 2009).
Search strategies are reported in full in Appendix 1.

Searching other resources

During the initial review process, primary authors of relevant studies and experts in the field were contacted. Proceedings from relevant conferences (ICADTS 1995, 2000) and a symposium on GDL were examined. Finally, reference lists of all potentially eligible studies were examined for further relevant articles.

Data collection and analysis

A medical librarian with experience in systematic reviews completed and collated the electronic search results.

Selection of studies

The selection of studies involved two steps. First, the initial search results of all databases and reference lists were screened independently by two investigators (original: LH, KR; update: LH, KR, JS, ES) to identify citations with potential relevance. Second, the full text of selected articles was obtained. Two reviewers (original: LH, JP, or KR; update: LH, KR) independently decided on study inclusion, using a standard form with pre-determined eligibility criteria. Disagreements were resolved by consensus or by a third party when necessary.

Data extraction and management

Data were extracted by two investigators (original: KR, NW; update: MK) and checked by a second investigator (original: LH, KR, or NW; update: KR, BV). A standard form was used that described the following: characteristics of the study (e.g. design); target population (age groups); interventions (description of GDL system, timing of intervention, co-interventions); outcomes (types of outcome measures, timing of outcomes); data sources; and, results. There were several studies that examined the same jurisdiction. In general, the primary study was defined as either the most recent study, the peer-reviewed study (opposed to internal document or grey literature), the study with a control group, or the study that examined the greatest span of years. If additional outcomes or different denominators were reported in secondary studies, these outcomes were included. Studies that examined an original and a revised GDL program, respectively, for the same jurisdiction were treated as two studies.

Assessment of risk of bias in included studies

The assessment of quality for observational studies is an area of ongoing discussion. To our best knowledge, there is only one tool that has been developed and tested for the assessment of methodological quality of both randomized and non-randomized studies (Downs 1998). This tool does not specifically address ecological studies, and the authors of the tool have recognized that further improvement of the instrument is required. Other researchers have developed scales for the purposes of specific reviews. These have not, however, been validated and are not widely applicable to other topics of study (e.g. Elvik 2001; Rivara 1999).
In assessing quality of the component studies, our overriding premise was that ecological studies are among the methodologically weaker study designs. Quality was assessed based on threats to the validity of ecological studies as presented by Hingson (Hingson 2001):

- measurement error: objective versus subjective data sources, e.g. police reports versus self-reports
- control groups: no control groups, internal controls (within the same jurisdiction, e.g. drivers 25-54), external controls (comparing two different jurisdictions), both internal and external controls
- statistical methods: no multivariable methods to control for confounding, multivariable modelling, time-series analysis
- confounding: confounders neither controlled nor discussed, confounders discussed, confounders controlled through analyses
- regression to the mean: number of years examined pre and post-implementation of GDL.

We also assessed the quality of the GDL program using the Classification of Licensing Systems from the Insurance Institute for Highway Safety (IIHS 2000). The IIHS system classifies GDL programs into one of four categories: good, fair (previously referred to as 'acceptable'), marginal, or poor. Criteria for each category are as follows.
Good:

- mandatory learner's permit holding period of at least six months, *and*
- optimal restriction on the initial license: either an optimal night driving restriction (curfew begins before midnight) or an optimal passenger restriction (no extra passengers unless supervised) lasting until age 17.

Fair (previously referred to as 'acceptable'):

- optimal restrictions lasting until age 17 with regard to the learner's holding period (minimum of six months), *or*
- any mandatory learner's holding period and any night driving or passenger restriction (during the intermediate stage) lasting at least until age 16½.

Marginal:

- at least one significant element of graduated licensing.

Marginal systems include: (i) both a mandatory learner's holding period that may be less than six months and either a night

driving or passenger restriction during the intermediate stage; or (ii) only an optimal mandatory learner's holding period (at least six months); or (iii) any night driving or passenger restriction on the intermediate license.

Poor:

- no mandatory learner's holding period
- no night driving or passenger restrictions during the intermediate stage, *or*
- mandatory learner's holding period less than six months and no other significant elements of graduated licensing.

GDLs were classified by the IIHS system; this was not used to define GDL but to ascertain the strength of the program. While the IIHS would classify a two-staged licensing program as GDL and define it as either a marginal or poor program, two-stage licensing programs were not included in this review.

Two reviewers (original: LH, NW, update: MK, KR) independently assessed both study quality and program quality. Quality was assessed based on information provided in the written report. For the newly added studies that were conducted in the United States, the IIHS classification was determined from their website which describes each state's GDL program (IIHS 2011). When studies were conducted outside the United States, the above criteria were applied to the study. The criteria could not be applied to the studies that examined the majority of American states. Differences were resolved by consensus.

Data synthesis

Percentage change was calculated for each year after the intervention year, using one year prior to the intervention as the baseline rate. Baseline rates were calculated using two denominators based on what was reported in the original study: per 10,000 population or per 10,000 licensed drivers. We did not evaluate the intervention year itself because of fluctuations in licensing rates immediately prior to and following program implementation, and to allow for a minimum amount of time for individuals to progress to the intermediate stage of licensure (Shope 2001); this is a standard approach in this type of evaluation (Foss 2001). There was one exception to this: Foss 2001 implemented their program in December of 1997 and omitted 1998 data from their analysis. We analyzed their results accordingly. In addition, Ohio 2001 provided results for 1999 only. Since the second phase of the intervention was implemented in January 1999 we did not include these results in our analysis.

Percentage changes were either calculated directly from rates or from raw numbers. Some data were extracted from graphs (Foss 2001; Frith 1992; O'Connor 2000; Masten 2004; Rios 2006), or derived from other summary statistics (Chaudhary 2007; Frith 1992; Hyde 2005; Shope 2001; Smith 2001). Additional data came from authors (Agent 2001; Langley 1996; McKnight 1983) and from an online government source (McKnight 1983).

Results from the component studies were not pooled due to statistical heterogeneity and differences among studies with respect to study quality and design, program quality and design, definition of outcomes, baseline rates, and data reported. Percentage change was selected as the summary measure, as it can be compared across studies regardless of baseline rates. Results for the first and last years that were studied post-GDL implementation are presented. (Other post-implementation rates are available from the review authors on request.) As some studies only looked at one year post-implementation, we provided data for one year for all studies to facilitate comparisons across programs. Results were adjusted by internal controls when data were available. A variety of internal control groups was used across the studies (e.g. 18-24, 19+, 20+, 25+, 25-54 year-olds). Only a few studies had relevant, extractable data for external controls, therefore rates adjusted for external controls were not calculated. Results were calculated for teenagers and for 16 year-olds only. Analyses were stratified by the different denominators used for rate calculations in the component studies (i.e. population, number of licensed drivers). Unadjusted results are presented unless otherwise noted. Baseline rates were calculated per 10,000 persons. Results were calculated for the different crash types: overall, injury (fatal and non-fatal), fatal, night-time, alcohol, and those leading to hospitalization. Night-time and alcohol crashes were added as post-hoc outcomes, because they were commonly reported in the component studies.

The following example illustrates the calculation of rates and how these were adjusted for controls. The example uses data from Mayhew 2000 for all-cause crashes among 16 year-olds. The baseline rate (BR) was 387 per 10,000 population. The rate one year post-implementation (PR) was 256/10,000. The internal control group (25+) experienced a BR of 238/10,000 and a PR of 207/10,000. Percent changes (PC) were calculated as follows:

PC = ((PR - BR)/BR)*100 = ((256 - 387)/387)*100 = -34%

Thus, the unadjusted percent change for 16 year-olds is -34%. Percent change for the internal controls is ((207-238)/238 * 100) = -13%. The adjusted percent changes were calculated as follows:

$PC_{adj} = PC_{unadj} - PC_{25+} = -34 - (-13) = -34 + 13 = -21$

Thus, the adjusted percent change for 16 year-olds is -21%.

RESULTS

Description of studies

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

Results of the search

Thirty-four studies were deemed relevant for the review.

Included studies

Several studies evaluated GDL in the same jurisdiction (43 US states - 2 studies; 48 US studies - 2 studies; Georgia - 2 studies; Iowa - 2 studies; Michigan - 2 studies; North Carolina - 2 studies; Ontario - 2 studies; Oregon - 2 studies; New Zealand - 3 studies, California - 5 studies). All studies were included as they reported on different outcomes (e.g. injury crashes versus hospitalizations). The GDL programs varied substantially in terms of the minimum age, minimum holding periods, and restrictions and requirements at each stage (See Table 1 and Characteristics of included studies). Based on the IIHS classification scheme and the information provided in the written reports, the GDL programs in thirteen studies were good (Chaudhary 2007; Fohr 2005; Hyde 2005; Kellermann 2007; Kirley 2008; Males 2007; Margolis 2007; Masten 2004; O'Connor 2007; Kingham 2008; Rice 2004; Rios 2006), ten were fair (Foss 2001; Hallmark 2008; Mayhew 2000; Mayhew 2003; Neyens 2008; Ohio 2001; Shope 2001; Shope 2004; Smith 2001; Ulmer 2000), seven were marginal (Agent 2001; Boase 1998; Bouchard 2000; Frith 1992; Kingham 2008; Langley 1996; McKnight 1983), and one was poor (O'Connor 2000). Four studies could not be assessed because they included either 43 or 48 US states (Baker 2006; Chen 2006; Dee 2005; Morrisey 2006). All but one program (O'Connor 2000) had a minimum holding period for the learner's license; for eight programs the minimum holding period was at least six months (Agent 2001; Boase 1998; Bouchard 2000; Foss 2001; Ohio 2001; Shope 2001; Smith 2001; Ulmer 2000). All but four studies had a night driving restriction during the intermediate stage (Agent 2001; Bouchard 2000; Boase 1998; O'Connor 2000). However, the night driving restriction began before midnight in only seven of the studies (Foss 2001; Frith 1992; Kingham 2008; Langley 1996 Males 2007; Margolis 2007; O'Connor 2007) and only applied to younger drivers in an eighth study (Ulmer 2000). Fifteen studies did not have a passenger restriction during the intermediate stage (Agent 2001; Boase 1998; Bouchard 2000; Foss 2001; Hallmark 2008; Margolis 2007; Mayhew 2000; Mayhew 2003; McKnight 1983; Neyens 2008; Ohio 2001; O'Connor 2000; Shope 2001; Shope 2004; Ulmer 2000).

Risk of bias in included studies

A summary of the quality measures assessed is presented in Table 2. All of the relevant studies used ecological designs. All studies obtained data from routinely collected sources (e.g. police reports, hospital records, census bureau).

Six studies used both internal and external control groups to control for factors beyond the GDL program that may have affected outcomes (Chaudhary 2007; Kellermann 2007; Mayhew 2000; McKnight 1983; O'Connor 2000; Ulmer 2000). Two studies used only external control groups (Kingham 2008; Rios 2006). Five studies had no control groups (Hyde 2005; Mayhew 2003; Morrisey 2006; O'Connor 2007; Smith 2001). The remaining studies used internal control groups only.

Nine studies conducted ARIMA time series analyses (Chaudhary 2007; Hyde 2005; Langley 1996; Males 2007; Margolis 2007; Masten 2004; Mayhew 2000; McKnight 1983; Neyens 2008), four studies used negative binomial regression (Baker 2006; Chen 2006; Dee 2005; Morrisey 2006) and three studies performed multivariable modelling with Poisson regression (Foss 2001; Kirley 2008; Rios 2006). O'Connor 2000 performed multiple univariate regressions examining different time points at which the slope was allowed to change. The primary model was selected based on minimizing the mean squared error. Fohr 2005 conducted multivariable induced exposure modelling; this is the only study that used multivariable modelling and did not incorporate any time or seasonal variables in the analysis. Sixteen studies used no multivariable methods to control for confounding (Agent 2001; Boase 1998; Bouchard 2000; Frith 1992; Hallmark 2008; Kellermann 2007; Kingham 2008; Mayhew 2003; O'Connor 2007; Ohio 2001; Raymond 2007; Rice 2004; Shope 2001; Shope 2004; Smith 2001; Ulmer 2000).

All studies controlled for some potential confounders through the analysis. The factors most often controlled were changes in population through the calculation of population-based rates (Chaudhary 2007; Chen 2006; Dee 2005; Fohr 2005; Foss 2001; Frith 1992; Kellermann 2007; Kingham 2008; Kirley 2008; Langley 1996; Masten 2004; Males 2007; Mayhew 2000; Mayhew 2003; McKnight 1983; O'Connor 2000; Ohio 2001; Raymond 2007; Rice 2004; Rios 2006; Shope 2001; Shope 2004; Smith 2001; Ulmer 2000) and changes in licensing through the use of rates per licensed drivers (Agent 2001; Baker 2006; Boase 1998; Bouchard 2000; Foss 2001; Frith 1992; Hallmark 2008; Hyde 2005; Kirley 2008; Langley 1996; Margolis 2007; Mayhew 2000; Morrisey 2006; Neyens 2008; O'Connor 2007; Ohio 2001; Smith 2001). In addition, the majority of studies discussed other possible confounders and their potential impact on outcomes. These included but were not limited to: changes in exposure due to different rates of licensure (Agent 2001; Baker 2006; Bouchard 2000; Chen 2006; Foss 2001; Frith 1992; Hyde 2005; Kirley 2008; Langley 1996; Males 2007; Margolis 2007; Masten 2004; Mayhew 2000; Mayhew 2003; McKnight 1983; Neyens 2008; O'Connor 2000; Rios 2006; Shope 2001; Shope 2004; Smith 2001; Ulmer 2000); economic factors (Baker 2006; Chaudhary 2007; Chen 2006; Dee 2005; Frith 1992; Langley 1996; McKnight 1983; Morrisey 2006); other legislative changes (Bouchard 2000; Dee 2005; Morrisey 2006; O'Connor 2000); reductions in the target population (Langley 1996; McKnight 1983;); safety belt use (Dee 2005; Kellermann 2007; Males 2007; Morrisey 2006; O'Connor 2007; Rios 2006); and changes in definitions or reporting of crashes (i.e. Mayhew 2000 reported a change in the criteria for

reporting property-damage only crashes from $500 to $1000; McKnight 1983 reported that police became more selective in their investigation, and therefore reporting, of crashes over the study period due to budgetary constraints; O'Connor 2007 reported that the criteria for reporting property-damage only crashes increased in $100 intervals from $1200 to $1500 over four years; Hallmark 2008 stated that types of crashes that required reporting changed).

Fifteen studies examined three or more years pre- and post-implementation of the program (Agent 2001; Frith 1992; Kellermann 2007; Kingham 2008; Kirley 2008; Langley 1996; Males 2007; Masten 2004; Mayhew 2000; McKnight 1983; Neyens 2008; O'Connor 2000; Rios 2006; Shope 2004). Four studies examined 43 or 48 US states that implemented GDL programs at different times; however, the analysis was conducted over 11 years and would likely have captured three or more years before and after implementation (Baker 2006; Chen 2006; Dee 2005; Morrisey 2006). Chaudhary 2007 examined GDL programs in three US states and two of the three states analysed data three or more years pre- and post-GDL implementation.

Effects of interventions

Unadjusted and adjusted percent changes in rates of overall, injury, hospitalized, fatal, night-time, and alcohol crashes are provided in the Additional Tables. The two columns labelled "unadj % chge yr 1" and "adj % change yr 1" compare changes between the first year after program implementation to the last year prior to the year of implementation. The columns labelled "unadj % chge last yr" and "adj % change last yr" reflect changes between the last year evaluated post-implementation and the last year prior to implementation. Caution should be exercised when comparing results across jurisdictions. The use of percent change allows for comparisons regardless of differences in baseline rates. However, there are many factors that may account for the results; such as the program itself, the laws that existed pre-GDL, the level of enforcement and compliance with the restrictions, and the study methodology.

Overall crashes

All crash types included driver-involved fatal, injury, and property-damage only (PDO) crashes.

Sixteen year-old drivers

Sixteen studies examining fifteen programs in fourteen jurisdictions presented comparable data for all crash types among 16 year-old drivers (Table 3).

Population based rates

- Unadjusted first year post-GDL (nine studies, seven programs, six jurisdictions): 13% to 41% reduction, median 26% reduction
- Adjusted first year post-GDL (six studies, six programs, six jurisdictions): 6% to 29% reduction, median 11% reduction
- Unadjusted beyond first year post-GDL (six studies, four programs, four jurisdictions): 14% to 45% reduction, median 29% reduction
- Adjusted beyond first year post-GDL (five studies, seven programs, seven jurisdictions): 8% to 27% reduction, median 15.5% reduction

Licensed drivers based rates

- Unadjusted first year post-GDL (six studies, six programs, six jurisdictions): 11% increase to 79% reduction, median 10% reduction
- Adjusted first year post-GDL (three studies, three programs, three jurisdictions): 27% increase to 73% reduction, median 36% reduction
- Unadjusted beyond first year post-GDL (six studies, six programs, six jurisdictions): 11% increase to 74% reduction, median 34% reduction
- Adjusted beyond first year post-GDL (three studies, three programs, three jurisdictions): 11% increase to 74% reduction, median 34% reduction

All teenage drivers

Six studies (eight programs, eight jurisdictions) provided data for all teenage drivers (Table 4).

Population based rates

- Unadjusted first year post-GDL (three studies, two programs, two jurisdictions): 10 % to 20% reduction, median 15% reduction
- Adjusted first year post-GDL (two studies, two programs, two jurisdictions): 4% to 7% reduction, median 5.5% reduction
- Unadjusted beyond first year post-GDL (one study, one program, one jurisdiction): 13% reduction
- Adjusted beyond first year post-GDL (three studies, four programs, four jurisdictions): 1% increase to 16% reduction, median 9.5% reduction

Licensed drivers rates

- Unadjusted first year post-GDL (three studies, two programs, two jurisdictions): 6% to 25% reduction, median 15.5% reduction
- Adjusted first year post-GDL (two studies, two programs, two jurisdictions): 11% and 19% reduction, median 15% reduction
- Unadjusted beyond first year post-GDL (three studies, three programs, three jurisdictions): 5% to 36% reduction, median 20.5% reduction
- Adjusted beyond first year post-GDL (three studies, three programs, three jurisdictions): 4% to 27% reduction, median 15.5% reduction

No associations between post-GDL rates and baseline rates or study quality were observed. There were also no consistent patterns when examining results by the quality of the program.

Injury crashes (fatal and non-fatal injury)

Sixteen year-old drivers

Fourteen studies examining twelve programs in twelve jurisdictions presented comparable data for injury crashes among 16 year-old drivers (Table 5).

Population based rates

- Unadjusted first year post-GDL (ten studies, eight programs, eight jurisdictions): 10% to 43% reduction, median 25% reduction
- Adjusted first year post-GDL (eight studies, five programs, five jurisdictions): 6% to 41%, median 27.5% reduction
- Unadjusted beyond first year post-GDL (five studies, five programs, five jurisdictions): 14% to 35% reduction, median 32.5% reduction
- Adjusted beyond first year post-GDL (five studies, five programs, five jurisdictions): 2% to 46% reduction, median 21% reduction
- Adjusted beyond first year post-GDL (one study, three programs, three jurisdictions): 0.13/1000 to 0.44/1000 reduction, median 0.16/1000 reduction

Licensed drivers based rates

- Unadjusted first year post-GDL (two studies, two programs, two jurisdictions): 3% increase to 35% reduction, median 16% reduction
- Adjusted first year post-GDL (no studies): not assessed
- Unadjusted beyond first year post-GDL (three studies, three programs, three jurisdictions): 0.6 % to 39% reduction, median 33% reduction
- Adjusted beyond first year post-GDL (no studies): not assessed

All teenage drivers

Eight studies (ten programs, ten jurisdictions) provided data for all teenage drivers (Table 6).

Population based rates

- Unadjusted first year post-GDL (five studies, five programs, five jurisdictions): 8% to 25% reduction, median 13% reduction
- Adjusted first year post-GDL (five studies, five programs, five jurisdictions): 4% to 23% reduction, median 14% reduction
- Unadjusted beyond first year post-GDL (three studies, three programs, three jurisdictions): 18% to 22% reduction, median 22% reduction
- Adjusted beyond first year post-GDL (three studies, three programs, three jurisdictions): 7% to 36% reduction, median 20% reduction
- Adjusted beyond first year post-GDL (one study, three programs, three jurisdictions): 0.14/1000 increase to 0.21/1000 reduction, median 0.13/1000 reduction

Licensed drivers rates

- Unadjusted first year post-GDL (three studies, three programs, three jurisdictions): 11% to 27% reduction, median 14% reduction
- Adjusted first year post-GDL (one study, one program, one jurisdiction): 17% reduction
- Unadjusted beyond first year post-GDL (one study, one program, one jurisdiction): 13% reduction
- Adjusted beyond first year post-GDL (no studies): not assessed

Hospitalizations

Sixteen year-old drivers

Three studies examining three programs in three jurisdictions presented comparable data for injury crashes among 16 year-old drivers (Table 7).

Population based rates

- Unadjusted first year post-GDL (one study, one program, one jurisdiction): 41% reduction

- Adjusted first year post-GDL (one study, one program, one jurisdiction): 35% reduction
- Unadjusted beyond first year post-GDL (one study, one program, one jurisdiction): 44% reduction
- Adjusted beyond first year post-GDL (one study, one program, one jurisdiction): 28% reduction

Licensed drivers based rates

- Unadjusted first year post-GDL one study, one program, one jurisdiction): 27% reduction
- Adjusted first year post-GDL (no studies): not assessed
- Unadjusted beyond first year post-GDL (two studies, two programs, two jurisdictions): 15% to 41% reduction, median 28% reduction
- Adjusted beyond first year post-GDL (one study, one program, one jurisdiction): 37% reduction

All teenage drivers

Three studies (two programs, two jurisdictions) provided data for all teenage drivers (Table 8).

Population based rates

- Unadjusted first year post-GDL (three studies, two programs, two jurisdictions): 23% to 26% reduction, median 24.5% reduction
- Adjusted first year post-GDL (three studies, two programs, two jurisdictions): 19% to 20% reduction, median 19.5% reduction
- Unadjusted beyond first year post-GDL (three studies, two programs, two jurisdictions): 36% to 50% reduction, median 43% reduction
- Adjusted beyond first year post-GDL (three studies, two programs, two jurisdictions): 20% to 66% reduction, median 23% reduction

Licensed drivers rates

- Unadjusted first year post-GDL (one study, one program, one jurisdiction): 18% reduction
- Adjusted first year post-GDL (no studies): not assessed
- Unadjusted beyond first year post-GDL (one study, one program, one jurisdiction): 25% reduction
- Adjusted beyond first year post-GDL (no studies): not assessed

Fatal crashes

Sixteen year-old drivers

Fifteen studies examining ten programs and one assessment of 43 US states in nine jurisdictions and two assessments of 43 US states presented comparable data for all crash types among 16 year-old drivers (Table 9).

Population based rates

- Unadjusted first year post-GDL (eight studies, seven programs, six jurisdictions): 56% increase to 60% reduction, median 37% reduction
- Adjusted first year post-GDL (five studies, five programs, five jurisdictions): 56% increase to 160 reduction, median 38% reduction
- Unadjusted beyond first year post-GDL (nine studies, six programs, five jurisdictions): 8% to 38% reduction, median 23% reduction
- Adjusted beyond first year post-GDL (seven studies, four programs and one assessment 43 US states, five jurisdictions and one assessment 43 US states): 1% to 110% reduction, median 18% reduction

Licensed drivers based rates

- Unadjusted first year post-GDL (five studies, four programs and one assessment 43 US states, four jurisdictions and one assessment 43 US states): 14% to 73% reduction, median 43% reduction
- Adjusted first year post-GDL (one study, one program, one jurisdiction): 59% reduction
- Unadjusted beyond first year post-GDL (four studies, four programs, four jurisdictions): 9% to 76% reduction, median 51.5% reduction
- Adjusted beyond first year post-GDL (two studies, two programs, two jurisdictions): 11% to 55% reduction, median 33% reduction

All teenage drivers

Nine studies (six programs and two assessments of multiple US states, six jurisdictions and two assessments of multiple US states) provided data for all teenage drivers (Table 10).

Population based rates

- Unadjusted first year post-GDL (three studies, two programs, two jurisdictions): 10% to 23% reduction, median 16.5% reduction
- Adjusted first year post-GDL (two studies, two programs, two jurisdictions): 15% to 57% reduction, median 36% reduction
- Unadjusted beyond first year post-GDL (five studies, four programs and one assessment 48 US states, four jurisdictions and one assessment 48 US states): 4 to 64% reduction, median 16% reduction
- Adjusted beyond first year post-GDL (four studies, four programs, four jurisdictions): 2% increase to 18% reduction, median 30.5% reduction

Licensed drivers rates

- Unadjusted first year post-GDL (two studies, two programs, two jurisdictions): 26% to 33% reduction, median 29.5% reduction
- Adjusted first year post-GDL (two studies, two programs, two jurisdictions): 6% to 19% reduction, median 12.5% reduction
- Unadjusted beyond first year post-GDL (two study, one program and one assessment 43 US states, one jurisdiction and one assessment 43 US states): 7 to 39% reduction, median 23% reduction
- Adjusted beyond first year post-GDL (one study, one program, one jurisdiction): 18% reduction

Night-time crashes

Sixteen year-old drivers

Five studies examining four programs in four jurisdictions presented comparable data for night-time crashes among 16 year-old drivers (Table 11).

Population based rates

- Unadjusted first year post-GDL (five studies, four programs, four jurisdictions): 25% to 50% reduction, median 43.5% reduction
- Adjusted first year post-GDL (one study, one program, one jurisdiction): 37% reduction
- Unadjusted beyond first year post-GDL (four studies, three programs, three jurisdictions): 50% to 64% reduction, median 58% reduction
- Adjusted beyond first year post-GDL (one study, one program, one jurisdiction): 51% reduction

Licensed drivers based rates

- Unadjusted first year post-GDL (three studies, three programs, three jurisdictions): 6% increase to 33% reduction, median 20% reduction
- Adjusted first year post-GDL (no studies): not assessed
- Unadjusted beyond first year post-GDL (three studies, three programs, three jurisdictions): 33% to 43% reduction, median 42% reduction
- Adjusted beyond first year post-GDL (no studies): not assessed

All teenage drivers

Three studies (three programs, three jurisdictions) provided data for all teenage drivers nighttime crashes (Table 12).

Population based rates

- No study calculated population based nighttime crash rates

Licensed drivers rates

- Unadjusted first year post-GDL (three studies, three programs, three jurisdictions): 3% to 48% reduction, median 32% reduction
- Adjusted first year post-GDL (no studies): not assessed
- Unadjusted beyond first year post-GDL (one study, one program, one jurisdiction): 14% reduction
- Adjusted beyond first year post-GDL (no studies): not assessed

Alcohol-related crashes

Data were presented on alcohol-related crashes (Table 13; Table 14) for four jurisdictions with zero tolerance for BAC. For 16 year-olds, two studies provided per population reductions: 16% (adjusted 2%) and 38% for the first year post-GDL. Rates in other years post-implementation were similar. Shope 2001 noted that the lack of substantial change in alcohol-related crashes over the three years studied was likely due to the zero tolerance law that was instituted prior to the study period. For all teenage novice drivers, Boase 1998 found a rate reduction per licensed driver of 19%. Bouchard 2000 evaluated the change in number of victims killed or injured in night-time single-vehicle crashes (21:00-06:00) as a proxy for alcohol-related crashes. Among learner and probationary drivers, the numbers decreased by 12% for two years post-GDL versus two years pre-GDL. There was a net decrease of 9% when adjusting for the 18-24 year-old internal control group. The authors considered these results to be preliminary as the outcome is not a perfect proxy for alcohol-related crashes.

Two additional studies presented data on alcohol-related crashes but the jurisdictions did not have zero tolerance for BAC: these had BAC restrictions of 0.02 (Agent 2001) and 0.03 mg/dl (Frith 1992). Agent 2001 found a per licensed driver rate reduction of 39% for 16 year-olds; this was similar two and three years post-GDL. Among 16-19 year-old drivers, he showed an increase per licensed driver of 15% in the first year post-GDL and zero and 4% decrease in the subsequent years post-GDL. Frith 1992 presented data on the degree of compliance with GDL restrictions, by comparing crash rates between 15-19 year-old drivers on a full or restricted license over a three year period post-GDL (1988-1990): drivers with a restricted license had 23% fewer crashes where alcohol-involvement was suspected.

Teen passengers

Two studies evaluated the effectiveness of a restriction on teen passengers (Chaudhary 2007; Smith 2001).

Chaudhary 2007 used a time series analysis to calculate crash rates among 16 year-old drivers driving with teen passengers in California, Massachusetts, and Maryland and their matched control state. After the California law change, there was a near significant reduction in crashes among 16 year-olds driving with young passengers and this resulted in crash reduction of 6/100,000 population. For Massachusetts two-vehicle crashes, it was not possible to determine which car the teen passenger was riding in. However, there was a significant reduction in single vehicle crashes driven by 16 year-old drivers with passengers (13/100,000 population per month). Virginia GDL allowed 16 year-old drivers to drive with only one passenger younger than 18 years of age. After the law change, there were significantly fewer 16 year-old drivers involved in crashes carrying two or more passengers (2.9/100,000 population per month).

Smith 2001 calculated the injury rate for teen passengers (15-19) who were injured or killed while riding with 16 year-old drivers. During the first year post-GDL, the rate per licensed driver decreased by only 3%. During the second year post-GDL, the observed decrease was 23%. Likewise, the passenger injury rate per population did not change substantially during the first year post-GDL (11% reduction), but did decrease significantly two years post-GDL (41%). Smith 2001 concluded that the reductions show there was compliance with the passenger restriction.

Convictions/suspensions

Boase 1998 presented data on convictions post-GDL by license level, but did not make any comparisons with pre-GDL measures. McKnight 1983 conducted a time series analysis of convictions from 1975-1982 (GDL implemented in 1979). The analysis of convictions for 16 year-olds, which incorporated the 18-21 year-old control group, showed a significant decline of approximately 10%, which coincided with the implementation of GDL. The pattern of changes in convictions for 17 year-olds paralleled that which was seen for 16 year-olds but did not reach statistical significance.

Rios 2006 compared the driving history of 21 year-olds who were involved in fatal crashes before (1997) and after GDL (2002). There was a significant reduction in history of speeding convictions (-61.1%), other dangerous driving convictions (-67.1%), and license suspensions (-72.5%) among 21 year-old drivers in fatal crashes in 2002 compared with 1997. There was no significant difference in history of alcohol convictions (-77.3%).

Property damage

Two studies examined property damage costs (Boase 1998; O'Connor 2007). Boase 1998 compared the property damage costs for 1993 and 1995 novice drivers followed for two years pre and post-GDL. The cost savings were $22 million, representing a 33% decrease in costs. Property damage included vehicles and contents, transportation infrastructure, buildings and other property, and environmental damage.

O'Connor 2007 noted that the number of crashes involving property damage among 16 and 17 year-old drivers significantly decreased after GDL was implemented in Delaware on July 1, 1999 (pre-GDL: 11.9%; post-GDL: 8.6%). However, minimum amount of property damage required for a police report varied throughout the study period from $1200 in 1998 to $1500 in 2001.

Comparisons of denominators and age groups used

When comparing results for different denominators and age groups, only within jurisdiction (direct) comparisons have value because there are too many other confounders between studies. Four studies provided results for both population and licensed driver denominators, thus allowing for direct comparisons (Foss 2001; Kirley 2008; Langley 1996; Smith 2001). Percent change decreases were consistently smaller using licensed drivers as the denominator for all outcomes where direct comparisons were possible (16 year-old overall crashes (Table 4), 16 year-old injury crashes (Table 6), 16 year-old and all teenage hospitalizations (Table 7; Table 8), 16 year-old fatal crashes (Table 9), 16 year-old night crashes (Table 11), and passengers injury rates with 16 year-old drivers).

All studies that examined both 16 year-olds separately and groups of teenagers consistently found smaller reductions for the teenage group as compared to the 16 year-olds (Agent 2001; Boase 1998; Chaudhary 2007; Fohr 2005; Frith 1992; Kellermann 2007; Kingham 2008; Langley 1996; Males 2007; Masten 2004; Mayhew 2000; Ulmer 2000).

Time series analyses

Seventeen studies employed multivariate modelling techniques: ARIMA (n=9), negative binomial regression (n=4), Poisson regression (n=3), and cut-point regression (n=1). These analysis methods adjust for secular and crash trends that may have been occurring irrespective of GDL implementation. These analysis methods also require at least three measurements of crash rates post-GDL. For these two reasons, these results are more robust than unadjusted and adjusted percent changes in crash rates. Regardless of the analysis technique, the majority of studies found a significant or near significant reduction in all crashes, injury crashes, hospitalizations crashes, and fatal crashes (Table 15). Four studies that used negative binomial regression techniques also examined the strength of GDL programs. Programs that received an IIHS rating of 'good' or included more GDL restrictions resulted in the largest crash reductions.

DISCUSSION

Overall, the evidence indicates that GDL is effective in reducing crash rates of teenage drivers, although the magnitude of the reduction varies. Several of the Bradford Hill criteria of causality were met (Bradford Hill 1965). First, there was a clear temporal relationship between the implementation of GDL programs and observed reductions. Second, the results were consistent: reductions were seen for all types of crashes among 16 year-olds and all teenage drivers, although the impact varied across jurisdictions. The effectiveness of GDL is supported by reductions in rates of all crash types and (almost entirely) consistent positive results across studies and within studies when adjusting for internal controls. Third, it is plausible that reducing driver exposure to high-risk situations would reduce crash rates. These findings are strengthened by studies conducted in the US that simultaneously examined the effectiveness of GDL programs in 43 (Chen 2006) or 48 (Dee 2005) states. The four studies found a reduction in fatal crashes among 16 year old drivers and all teenage drivers, regardless of denominator choice (i.e. population based or licensed drivers). While the results from across the studies were consistent, the majority of the studies were conducted in the US or Canada. The results and conclusions of this review may not be generalizable to other countries where licenses are purchased instead of earned or where the age of licensure differs.

While the principles underlying GDL are widely accepted, there is variability in the design and strength of different programs (Williams 2003a). Because of the political realities and different social environments, the programs accepted for implementation will vary. For example, jurisdictions with many rural communities may be reluctant to adopt an early night curfew that limits teenagers' ability to work or participate in school events. We hypothesized a priori that there may be a variation in effect between programs with more versus fewer components (e.g. dose-response relationship). We were unable to find any consistent patterns when examining the results by the quality of the GDL program; however, two unique recent studies from the US found that stronger GDL programs (either containing more restrictions or rated as 'good' by the IIHS) resulted in significantly fewer fatalities. Despite the structure of the programs, the research shows that all appear to be having positive effects.

GDL programs are continually evolving. For example, Maryland has strengthened their program by increasing the minimum holding time within each stage and added a passenger restriction. California increased the duration of night-time restriction from 00:00 to 23:00. The revised GDL programs allow for the unique opportunity to examine different components within the program within the same jurisdiction.

Due to issues related to logistics and feasibility, research in this area involves studies with an ecological design. A specific concern affecting the validity of results from ecological studies is the inability to fully control for other explanatory factors. For example, authors have questioned the extent to which the effects are attributable to GDL or to delayed licensure or reduced exposure (e.g. Agent 2001; Frith 1992; Langley 1996; Smith 2001). One of the simpler methods of controlling for changes in licensing is through comparison of rates based on the number of licensed drivers. There were six studies for which we had both population and licensed driver denominators for the same outcome. Among these studies, the changes were consistently smaller when using licensed drivers as the denominator. Readers should be aware of this when examining the results from different studies. While both denominators are valid and important, they are answering slightly different questions. Rates per licensed drivers demonstrate the direct effects of GDL legislation (Ohio 2001). Whereas population-based rates also capture the indirect effects of the legislation, such as driving exposure.

Many studies have attempted to control for other factors through the use of control groups and appropriate statistical techniques. As seen from the results presented in the tables, the calculations adjusting for internal controls are generally lower than the unadjusted values. Therefore, unadjusted values may overestimate the impact of the program. Internal controls are used to control for extraneous variables within the population under study that may explain the observed effects (e.g. other traffic safety legislation), while external controls will take into account variables acting at a regional level that are not related to graduated licensing (e.g. economic factors affecting the larger geographic area as a whole) (Agent 2001). While many of the studies attempted to control for important potential confounders, the role of some potential confounders has not been explored and may not be feasible. For example, the effects of road networking, speed limits, resources for patrolling the roads, and differences in road and safety culture have not been determined.

A limitation of some of the studies was the relatively short period of time evaluated post-intervention. Often there were dramatic increases in licensing rates immediately before the implementation of a program with a concomitant decrease immediately after. Studies with short follow-up periods may be reporting misleading findings. Calculation of collision rates per licensed drivers controls for changes in licensing. Nevertheless, long-term follow-up is essential in order to allow patterns to stabilize and to evaluate the full impact of a program. In addition, changes seen post-implementation may simply reflect the continuation of a pre-existing downward trend (Mayhew 2000). Specific analytic techniques (e.g. time series analyses) can account for the confounding effects of trends over time. A minimum of three years pre and post-intervention is required for statistical analyses to be feasible. A minimum of three years would also allow for the first full cohort to have completed the program. A number of studies conducted time series or other analyses that control for time trends and the results were generally conservative compared with the range of findings reported overall. A second limitation is that the population distributions within each jurisdiction were not standardized but the actual population. If the population structures differ, this will not be adjusted for in the calculation of the population based injury rates.

This review found that certain components (e.g. night-time curfews) showed a positive effect; however, we cannot directly compare programs with and without these specific components because of other confounders. It is of interest that the programs vary with respect to key elements that are empirically supported in the literature. For example, the evidence demonstrates that night curfews are effective in reducing crash rates; previous research has suggested that the optimal starting time is 21:00 or 22:00 (Foss 1999). Despite this evidence, only seventeen of the twenty-three programs had a night curfew during the intermediate phase and only three of the curfews began before midnight for all drivers. There is also evidence supporting restrictions on the number of passengers (Aldridge 1999; Chen 2000; Doherty 1998; Preusser 1998). However, eleven programs did not allow passengers when driving unsupervised during the intermediate stage. In contrast, driver's education has been shown to have few benefits in terms of reducing crash rates (Mayhew 1998). It is, however, an essential component in seven programs and in four programs minimum holding periods can be reduced with successful completion. In addition to identifying the individual GDL components that result in the greatest reduction of injuries, it is optimal to identify the chain or process of how injuries are reduced. For example, a strong GDL program may be ineffective without adequate and consistent enforcement. The studies did not provide adequate details to examine these process factors.

While it is desirable for a systematic review to provide an overall summary measure of the estimates of effect, it is not always appropriate. Meta-analysis was not possible due to differences in study populations (baseline rates, population sizes, age groups), methods (e.g. denominators used in rate calculations), outcomes (e.g. different definitions, different reporting thresholds), and the interventions (the programs themselves, other legislative changes, pre-existing legislation, and the extent of enforcement and compliance). Caution should be exercised when comparing results across studies because of the many factors that could influence crash rates. In order to compare study results for different programs, standard methods should be adopted for the evaluation of GDL. We are beginning to see this in the more recent literature as similar methods are being employed from one evaluation to the next. Despite the standardization of methods, the appropriateness of combining data from observational studies remains controversial. Finally, interpretation of study findings should account for the quality, or internal validity, of the study. Presently there are few validated instruments available for the assessment of methodological quality of observational studies and none to our best knowledge that specifically address ecological studies. In order to synthesize available evidence and interpret it in a judicious manner, there is a need to develop a valid tool to assess quality of different types of observational studies.

Summary

The existing evidence indicates that GDL, in its many forms, is effective in reducing crash rates of teenage drivers. The resulting savings in terms of lives and costs are indisputable. The relative contribution of different provisions within a GDL program remains uncertain but has been identified as a research priority in this area (Hedlund 2003) and would benefit from systematic review. The individual provisions may be less important than the overriding principle of gradually introducing new drivers to higher risk situations as they acquire more driving experience. Standard approaches to research methods and reporting would allow for a more equitable comparison of the relative impact of different GDL programs.

AUTHORS' CONCLUSIONS

Implications for practice

- The existing evidence shows that GDL is effective in reducing crash rates of young drivers. However, the magnitude of the effect is not consistent across jurisdictions due to a range of factors.

- The relative contribution of different provisions within a GDL program requires focused research and review.

Implications for research

- In general, GDL programs are effective and future research needs to be designed to determine the relative impact of different components.

- Primary research on GDL should focus on analyses that account for potential confounders and trends over time, standardized reporting of outcomes and results, and long-term follow-up.

- There is a need for the development and validation of methods for assessing the methodological quality of different types of observational studies.

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* *Indicates the major publication for the study*

CHARACTERISTICS OF STUDIES

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

Agent 2001

Methods	Ecological design: single group studied over time Years studied: 1997-99 versus 1993-95
Participants	Primary: 16 yo (data presented for 16-16.5, 16.5-17) Secondary: 17 Control: 19 yo, >19 yo (some data presented for 18 yo) Program applies to drivers < 18
Interventions	Oct 1996 Level 1: min age 16; min holding period 6 mos; supervision (licensed driver 21+); no driving 00:00-06:00 (exemptions available); lower demerit threshold with penalty of license suspensions for violations Level 2: min age: 16,6 mos; driver's ed required within first year; lower demerit limit with penalty of license suspensions for violations; intermediate stage lasts until age 18 Lower BAC for all drivers <21 (<=0.02 mg/dl)
Outcomes	Drivers involved in all crashes (fatal, non-fatal, property damage only crashes) reported to state police Fatal crashes Injury crashes Night-time crashes (00:00-06:00) Alcohol-related crashes (additional data provided by authors) Describe crash characteristics post-GDL with respect to teenage passengers and seatbelt use; provide cost data
Notes	Kentucky

Baker 2006

Methods	Cross-sectional study: comparing two or more populations at the same time point Years studied: 1994-2004
Participants	Age group studied:16 yo Control: 20-29 yo drivers
Interventions	Program implemented at different time points Presence or absence of 7 GDL components were examined: minimum age for learner permit, mandatory waiting period, minimum hours of supervised driving, minimum entry age for intermediated stage, night-time restriction, passenger restrictions, minimum age for full licensing minimum age for full licence States divided into quarters for each year and classified as having a GDL or not having a GDL
Outcomes	Fatal crashes
Notes	43 states in the United States (excluding District of Columbia, Maine, New Hampshire, Rhode Island, Utah and Virginia) This is the secondary study and Chen 2006 is the primary study

Boase 1998

Methods	Ecological design: single group studied over time Years studied: 1995/96 versus 1993/94 (all novice drivers); additional analyses on all crashes and fatal crashes presented for 16 yo and 16-19 yo only for 1988-1996 (6 years pre and 2 years post-intervention)
Participants	Data presented on all novice drivers (16-19, 20-24, 25-34, 35-44, 45-54, 55+), however only 16-19 novices used for this review; some data presented for 16 yo alone; control group: general driving population GDL applies to all novice drivers
Interventions	Apr 1994 Level 1: min age 16; min holding period 12 mos (8 mos with driver ed); supervision (fully licensed driver with 4+ yrs experience and BAC <0.05%); vision test; knowledge test; supervisor only other occupant in front seat; number of passengers in rear seat does not exceed number of seatbelts; zero BAC; no driving 00:00-05:00; no driving on designated freeways; restrictions on type of vehicle allowed to drive; must pass on-road exam to enter next level; Level 2: min age 16, 8 mos; min holding period 12 mos; number of passengers must not exceed number of seatbelts; zero BAC; restrictions on type of vehicle allowed to drive; min age next stage 17,8 mos; must pass advanced level road test to enter next stage
Outcomes	All crashes (reportable collisions as filed by police officers) Fatal crashes Injury crashes Fatal and injury crashes combined Crashes with property damage only Subgroup analyses for age group, gender, and level of license (i.e. level 2 drivers only) Alcohol-related crashes (BAC of driver above legal limit) Night-time crashes (00:00-05:00) Freeway crashes (400 series highways) Compares level 2 drivers with and without driver's education certificate Presents information on convictions and cost-savings
Notes	Ontario

Bouchard 2000

Methods	Ecological design: single group studied over time Years studied: July 1997-June 1999 versus 1995-96
Participants	Learner and probationary drivers Control: 18-24 yo regular license holders Program applies to new drivers <25 yo
Interventions	Jul 1997 (reform) Level 1: min age 16; min holding period 12 mos (8 mos with driver ed); supervision (holder of valid license for 2+ yrs); driving knowledge test; lower demerit threshold; zero BAC with license suspension and fine for violation; Level 2: min age 16,8 mos; min holding period 24 mos or until age 25; zero BAC with license suspension and fine for violation; lower demerit threshold; min age next stage 18,8 mos
Outcomes	Number of victims killed and number of victims injured in crashes involving learners or probationary drivers (from provincial insurance society) Night-time single vehicle crashes (21:00-06:00) were examined as a proxy for alcohol-related crashes

Bouchard 2000 (*Continued*)

Notes	Quebec

Chaudhary 2007

Methods	Controlled before-after study: outcomes are measure before and after the intervention and an appropriate control group is used Years studied: California - 1995-2003; Massachusetts - 1995-2003; Virginia - 1999-2003
Participants	Age groups studied: 15-19 yo Controls: Arizona for California, Connecticut for Massachusetts, Marlyand for Virginia
Interventions	California - July 1998; Massachusetts - Nov 1998; Virginia - July 2001 California Level 1: minimum 6mo, 15.5 yo, 50 hrs of supervised driving (10 hrs of which are at night) Level 2: 16 yo, no passengers <20yo unless supervised by a driver >24yo for 6mo or until driver is 17yo, no driving between 00:00-5:00 until 16.5 yo Massachusetts Level 1: minimum of 6 mo, 16 yo, 12 hrs of supervised driving Level 2: no passengers younger than 18yo for the first 12 mo, no driving between 00:00-5:00 Virginia Level 1: minimum of 9mo, 15.5 yo, 40 hrs of supervised driving (0 hrs of which are at night) Level 2: only one passenger <18yo during the first 12mo, no driving between 00:00-4:00
Outcomes	Crashes Injury crashes
Notes	California, Massachusetts, Virginia This is one of the secondary studies (California only) along with Masten 2004, Smith 2001, Rice 2004; the primary study is Males 2007

Chen 2006

Methods	Cross-sectional study: comparing two or more populations at the same time point Years studied: 1994-2004
Participants	Age group studied:16 yo Control: 20-29 yo regular licence holders
Interventions	Program implemented at different time points Presence or absence of 7 GDL components were examined: minimum age for learner permit, mandatory waiting period, minimum hours of supervised driving, minimum entry age for intermediated stage, minimum age for full licensing minimum age for full licence, night-time restriction, passenger restrictions States divided into quarters for each year and classified as having a GDL or not having a GDL
Outcomes	Fatal crashes

Chen 2006 (*Continued*)

Notes	43 states in the United States This is the primary study and Baker 2006 is the secondary study

Dee 2005

Methods	Controlled before-after: outcomes are measured before and after the intervention and an appropriate control is used Years studied: 1992-2002
Participants	Age studied: 15-17 yo Control group:18-26 yo
Interventions	Program implemented at different time points Common elements from all programs Level 1: young drivers can only drive in the presence of a licensed driver over the age of 21, typically required to stay at this level for at least 6 months, and the driver must log 30-60 hours of supervised driving Level 2: young driver is allowed to operate a vehicle without supervision from daylight to early evening hours (e.g. , 05:00-22:00), typically allowed to have no more than one or two passengers in the car; full privilege phase begins upon the successful completion of the earlier phases and at minimum age as high as 18
Outcomes	Fatal crashes Fatal crashes for good, fair, marginal, and poor programs Fatal crashes for speeding Fatal crashes for alcohol related (0.10 BAC and 0.08 BAC), and zero tolerance Fatal crashes for seatbelt law as primary or secondary enforcement
Notes	48 United States (excluding Alaska, Hawaii, and DC) This is the primary study and Morrisey 2006 is the secondary study

Fohr 2005

Methods	Years studied:1999, 2002, 2003
Participants	Age group studied:16, 17, 18 yo Control group: 25-59 yo
Interventions	Sept 2000 Level 1: minimum age of 15.5 yr, drive under the supervision of an experienced adult, 30 hours of practice driving of which 10 must be at night, hold learners fr a minimum of 6 months Level 2: no driving between 00:00-05:00 unless accompanied by an adult or are driving between work, school, and home, passengers limited to 1 unrelated passenger less than 21 yo, minimum of 9 months, violation of these restrictions or a moving traffic violation conviction may result in an extension of the restrictions
Outcomes	All crashes Injury crash rates
Notes	Wisconsin

Foss 2001

Methods	Ecological design: single group studied over time Years studied: 1999 versus 1996 and 1997
Participants	Age group studied: 16 yo Control group: 25-54 Program applies to 15-17 yo
Interventions	Dec 1997 Level 1: min age 15; min holding period 12 mos; supervision by parent/guardian; vision test; driver ed; written and sign test; all occupants belted; conviction-free final 6 mos; first 6 mos no driving 21:00-05:00 Level 2: min age 16; min holding period 6 mos; road test prior to level 2; no unsupervised driving 21:00-05:00; supervision by parent / guardian when driving between 21:00-05:00; all occupants belted; final 6 mos violation-free; Level 3: min age 16.5; all occupants belted (Additional information on programme from Foss 2000)
Outcomes	Crashes for all drivers of passenger vehicles (all reportable crashes involving fatality, personal injury or property damage >= $1000) Fatal, serious injury, minor or no injury crashes Day/night (21:00-04:59) crashes Single vs multiple vehicle crashes Alcohol use by driver More vs less rural driving environment
Notes	North Carolina This is the secondary study and Margolis 2007 is the secondary study

Frith 1992

Methods	Ecological design: single group studied over time Years studied: 1981-1991 (primarily; although data presented varied with years ranging from 1980-1991, 1983-1991, 1985-1991)
Participants	Age group studied:15-19 (aggregated and separated by year); Control group: 25+ yo Program applies to 15-24 yo
Interventions	Aug 1987 Level 1: min age 15; min holding period 6 mos (3 mos with certificate of competency from driving instructor); supervision (20+ with full license for minimum of 2 yrs); vision and hearing test; written and oral test; “no alcohol”; Level 2: min age 15,3 mos; min holding period 18 mos (9 mos with driving course); road test prior to level 2; no unsupervised driving 22:00-05:00; no passengers unless supervised; “no alcohol”; license must be in car when driving; min age next stage 16 For both stages, violations of GDL conditions result in extensions of up to 6 months to the learner or restricted license
Outcomes	Drivers involved in reportable injury crashes (Ministry of Transportation data) Drivers admitted to hospital (hospital admissions data) Data on casualty and cost savings, compliance with restrictions

Frith 1992 (*Continued*)

Notes	New Zealand This is one of the secondary studies and Langley 1996 is the other secondary study and Kingham 2008 is the primary study

Hallmark 2008

Methods	Controlled before-after: outcomes are measured before and after the intervention and an appropriate control group is used Years studied: 1995-2004 (crashes from 1999 and 2001 were excluded)
Participants	Age studied: 14-17 yo Control group: 35-44 yo
Interventions	Jan 1999 Level 1: 14 yo, supervised by licensed adult driver, complete 20 hours of supervised driving (2 hours between sunrise and sunset). Hold for a minimum of 6 months and drive crash and conviction free for 6 consecutive months and be crash and conviction free for 6 consecutive months immediate preceding application for an intermediate licence and complete drivers education (30 hours classroom and 6 hours of driving), passengers limited to number of seatbelts Level 2:16 yo and hold for 12 months, supervised by a licensed driver between 00:30-05:00, 10 hours of supervised driving wit a minimum of 2 hours from sunrise to sunset. If the driver commits a moving violation or contributes to a crash, they must attend remedial driver interview with the Department of Transportation and begin the year long intermediate stage again, passengers limited to number of seatbelts Level 3: 17 yo Co-intervention: Minor School Licensing: 16 yo and younger can drive unaccompanied to and from the school of attendance and school-endorsed activities
Outcomes	Police reported crashes
Notes	Iowa This is the secondary study and Neyens 2008 is the primary study

Hyde 2005

Methods	Ecological design: single group studied over time Years studied: 1996-2001
Participants	Age studied: 16 yo
Interventions	July 1999: all new drivers must complete 30 hours of driving with parent guardian, or licensed adult spouse and at least 10 hours after dark, anyone less than 17 yo may not drive from 00:00-05:00 July 2000: all occupants less than 19 yo must be properly restrained July 2001: for the first 6 months of licensure, teenage drivers may have passengers <21 yo only if there is an adult driver in the front seat of the vehicle Level 1 and 2 were not described
Outcomes	Crash rates Night-time crash rates

Hyde 2005 (*Continued*)

Notes	Utah

Kellermann 2007

Methods	Controlled before-after: outcomes are measured before and after the intervention and an appropriate control group is used Years studied: 1992-2002
Participants	Age studied: 16 yo Control group: 21-24 yo, also compared to South Carolina, Tennessee, and Alabama
Interventions	July 1997 Level 1: minimum 12 mo, 15 yo, not convicted for a DUI, hit-and-run, leaving the scene of a crash, or any other offence for which four or more points are assessed, complete an approved driver education course and 20 hours of supervised driving (6 hrs at night) or complete 40 hrs of supervised driving (6 hrs at night) Level 2: minimum 12 mo,16 yo, no driving between 01:00-05:00 unless driving to work, school event, religious activity, medical, fire or law enforcement emergency. In 2001, night restriction from 00:00-6:00 with no exception. During first 6mo, passengers must be immediate family and after 6mo, only 3 passengers <21 yo who are not immediate family, not convicted for a DUI, hit-and-run, leaving the scene of a crash, or any other offence for which four or more points are assessed Level 3: 18 yo, full license
Outcomes	Fatal crashes (drivers, passengers, pedestrian)
Notes	Georgia This is the primary study and Rios 2006 is the secondary study

Kingham 2008

Methods	Controlled before-after: outcomes are measured before and after the intervention and an appropriate control group is used Years studied: 1980-2001
Participants	Age studied: 15-18 yo Control group: Great Britain
Interventions	Aug 1987 Level 1: minimum 6 mo, accompanied by a supervisor (current full drivers license for at least 2 years), no driving from 22:00-05:00, very low BAC limit Level 2: minimum 12 mo, drive without supervision but same restrictions as Level 1 Level 3: Full license - permitted to drive at all times with passengers
Outcomes	Fatal crashes
Notes	New Zealand This is the primary study and Frith 1992 and Langley 1996 are the secondary studies

Kirley 2008

Methods	Controlled before-after: outcomes are measured before and after the intervention and an appropriate control group is used Years studied: 1996-2003
Participants	16 yo Control group: 30-59 yo
Interventions	July 1999 Level 1: minimum 4 mo, 40 hrs of supervised driving, remain free of traffic convictions Level 2: minimum 18 mo, non-supervised night restrictions from 00:00-05:00
Outcomes	Crashes Non-fatal injuries Fatalities
Notes	Maryland

Langley 1996

Methods	Ecological design: single group studied over time Years studied: 1978-1992
Participants	Primary: 15-19 Secondary: 20-24 Control groups: 25+, as well as two non-traffic injury groups 15-19 yo (struck by/against, assaults) program applies to 15-24 yo
Interventions	Aug 1987 Level 1: min age 15; min holding period 6 mos (3 mos with certificate of competency from driving instructor); supervision (20+ with full license for minimum of 2 yrs; sits in front seat); vision test; written and oral test; 0.03 BAC; must have license in car when driving; Level 2: min age 15,3 mos; min holding period 18 mos (9 mos with driving course); road test prior to level 2; no unsupervised driving 22:00-05:00; no passengers unless supervised; 0.03 BAC; license must be in car when driving; min age next stage 16 For both stages, violations of GDL conditions result in extensions of up to 6 months to the learner or restricted license
Outcomes	Discharges from public hospitals (including drivers and passengers; excluding readmissions for same injury)
Notes	New Zealand This is one of the secondary studies and Frith 1992 is the other secondary study and Kingham 2008 is the primary study

Males 2007

Methods	Controlled before-after: outcomes are measured before and after the intervention and an appropriate control group is used Years studied:1995-2005
Participants	Age studied: 16-19 yo (GDL applies to 16 and 17 yo) Control group: 20-44 yo
Interventions	July 1998 Level 1: 6 months minimum, complete 50 hrs of driving (minimum 10 hrs at night) supervised by parent, spouse, adult >24 yo, or driver instructor, complete drivers education and drivers training course, no driving between 00:00-5:00, or transport passengers <20 unless supervised Level 2: 12 month minimum or until 18th birthday, passes advanced driver training and behind-the-wheel test, no passengers under age 20 between 00:00-05:00 unless supervised Amendments on Jan 1, 2006: driver restriction increased to 23:00-05:00, and transport passengers <20 yo for one year (increased from 6 mo) Level 3: complete Level 1 and 2, and no outstanding DMV or court-ordered restrictions, suspensions, or prohibitions
Outcomes	Driver fatalities
Notes	California This is the primary study and the secondary studies are Masten 2004, Rice 2004, Smith 2001, and Chaudhary 2007 (California only)

Margolis 2007

Methods	Controlled before-after: outcomes are measured before and after the intervention and an appropriate control group is used Years studied: 1996-2001
Participants	Age studied: 16 to 17 yo Control group: 25-54 yo
Interventions	Dec 1997 Level 1: age 15 and passed mandatory driver education course, drive for 12 months while supervised by a parent or guardian or designated person who has been licensed for at least five years Level 2: drive without supervision between 05:00-21:00, after a minimum of 6 months without a traffic violation, teens can get a full license
Outcomes	Hospitalisation rates Hospital costs
Notes	North Carolina This is the primary study and Foss 2001 is the secondary study

Masten 2004

Methods	Controlled before-after: outcomes are measured before and after the intervention and an appropriate control is used Years studied: 1994-2001
Participants	Age group studied:15-17 yo Control group: 24-55 yo
Interventions	June 1998 Level 1: 6 months instruction permit period, parent/guardian certification that the teen driver completed a minimum of 50 hours of practice (10 hours after dark) supervised by a licensed parent/guardian, spouse, adult 25 yo or older, or certified driving instructor Level 2: 6 month restriction from driving with passengers under the age of 20 and12 month restriction from diving between 00:00-05:00. Restrictions not in effect if supervised by person defined above unless they have signed permission to travel for school, employment of family emergency
Outcomes	Fatal/injury crashes Fatal/injury crashes at night Fatal/injury crashes with a passenger under age 20
Notes	California This is one of the secondary studies along with Rice 2004, Smith 2001, and Chaudhary 2007 (California only); the primary study is Males 2007

Mayhew 2000

Methods	Ecological design: multiple groups studied over time Years studied: 1995 and 1996 versus 1993; trend analysis from 1986-1997
Participants	Age groups studied: 16, 17, and all novice drivers Control groups: 25+, external jurisdictions Program applies to all novice drivers regardless of age
Interventions	Oct 1994 Level 1: min age 16; min holding period 6 mos (3 mos with driver ed); supervision by experienced driver who sits in front passenger seat; no other passengers; zero BAC; road test to enter next stage; Level 2: min age 16,3 mos; minimum holding period 24 mos; must complete defensive driving or driver training course; no unsupervised driving 00:00-05:00; only one other person in front seat; number of rear seat passengers limited to number of available seatbelts; zero BAC; min age next stage 18,3 mos License suspensions at either stage delay graduation to next stage by minimum time required at that stage
Outcomes	All driver-involved police reported crashes (fatalities, injuries, property damage only) Driver involved casualty crashes (fatal and injury crashes only; excluding PDO crashes)
Notes	Nova Scotia This is the secondary study and Mayhew 2003 is the primary study

Mayhew 2003

Methods	Ecological study: single population in which outcomes were measured before and after the legislation was implemented Years studied: 1992-1996
Participants	Age group studied:16 and 17 yo, and all novice drivers Program applies to all novice drivers regardless of age
Interventions	Oct 1994 Level 1: min age 16; min holding period 6 mos (3 mos with driver ed); supervision by experienced driver who sits in front passenger seat; no other passengers; zero BAC; road test to enter next stage; Level 2: min age 16,3 mos; minimum holding period 24 mos; must complete defensive driving or driver training course; no unsupervised driving 00:00-05:00; only one other person in front seat; number of rear seat passengers limited to number of available seatbelts; zero BAC; min age next stage 18,3 mos License suspensions at either stage delay graduation to next stage by minimum time required at that stage
Outcomes	Collision rates Collision rates during unrestricted hours Collision rates for those with and without drivers training Collision rates beyond 24-month intermediate phase
Notes	Nova Scotia This is the primary study and Mayhew 2000 is the secondary study

McKnight 1983

Methods	Ecological design: multiple groups studied over time Years studied: 1975-82
Participants	Primary: 16 yo Secondary: 17 Control: 18-21, external jurisdictions (national data; Virginia) Program applies to drivers <18 and use of passenger vehicles only
Interventions	Jan 1979 Level 1: min age 15,9 mos; min holding period 14 days (valid for 3 mos); supervision by licensed driver 21+; vision test; written test; Level 2: min age 16; min holding period 6 mos of violation-free driving or until 18; road test and driver ed to obtain level 2; no unsupervised driving 01:00-06:00 (exemptions available); lower demerit threshold with specific remedial action; any violation extends duration of level 2 by 6 mos; any violation results in driver improvement action; violation free for 6 mos prior to full license; minimum age next stage, 16, 6 mos Parent certificate indicating number of hours of supervised practice driving optional at both level 1 and 2
Outcomes	All crashes (fatal, injury, property damage only as reported by state police) by night-time (01:00-06:00) / daytime Occurrence Traffic convictions
Notes	Maryland

Morrisey 2006

Methods	Cross-sectional: comparing two or more populations at the same point in time
Participants	Age group studied: 15-17 yo
Interventions	1992-2002 Varied by state but typical program has a: learning phase where young drivers can only drive in the presence of a licensed driver over the age of 21, intermediate phase where the young driver can drive without supervision, but states may limit driving during the evening and late night hours or limit the number of passengers, and full licence phase occurring after the successful completion of the earlier phase and at a minimum age as high as 18
Outcomes	Fatal crashes Rural fatal crashes - interstate and non-interstate
Notes	48 states in the United States (excluding Hawaii, Alaska, and District of Columbia) This is the secondary study and Dee 2005 is the primary study

Neyens 2008

Methods	Controlled before-after: outcomes are measured before and after the intervention and an appropriate control group is used Years studied: 1995-2005 (first five months of 2005)
Participants	Age group studied: 16-17 yo Control group: 18 yo, 25-54 yo
Interventions	Jan 1999 Level 1: minimum of 20 supervised driving Level 2: 16 yo, 12-month intermediate licensing period with night time (00:30-05:30) and passengers equal to number of seatbelts Leel 3: 17 yo with no traffic violations during intermediate period Co-intervention: Minor School Licensing: 14.5 yo drivers can drive after they complete driver's education class, knowledge test, and a driving test but can only drive to and from school and after-school activities
Outcomes	Police reported crashes
Notes	Iowa This is the primary study and Hallmark 2008 is the secondary study

O'Connor 2007

Methods	Ecological design: single group studied over time Years studied: 1998-2002
Participants	16-17 yo
Interventions	July 1999 Level 1: minimum of 6 mo, at least 15 yr, 10 mo, passe certified drivers education, signed endorsement of sponsor, drive when supervised by someone at least 25 yo, licensed for 5 years, and seated in the front seat, maximum of two

O'Connor 2007 (*Continued*)

	passengers and supervisor Level 2: must be supervised from 22:00-06:00, maximum of 2 passengers (and supervisor during restricted hours)
Outcomes	Crashes Property damage Injuries EMS transports Hospitalization Fatal crashes Crashes at night Cost of injuries
Notes	Delaware

O'Connor 2000

Methods	Ecological design: multiple groups studied over time Years studied: 1983-1992
Participants	Age group studied: 16-19 yo drivers Control: 20+, 20-24, 25+, other jurisdiction (state of Victoria)
Interventions	Nov 1989 Level 1: min age 16; no min holding period; supervision (fully licensed driver); selective vision testing; Level 2: min age 16, 6 mos; min holding period 12 mos or until 19 - whichever was longer; max speed 100 kph; min age for next stage 19 Legislation in 1985 for zero BAC during level 2 Programme information from report and personal communication with author (O'Connor)
Outcomes	Driver fatalities Driver serious injuries (i.e. police reported hospitalizations)
Notes	South Australia

Ohio 2001

Methods	Ecological design: single group studied over time Years studied: a) 1988-1999; b) 1999 vs 1996 and 1997
Participants	Primary comparison: GDL group (15.5 yo on or after July 1, 1998 and 16 yo who received license under new GDL law) vs pre-GDL group (16 and 17 yo in 1996 and 1997); secondary comparison: 15, 16, 17 yo for 1988-1999 Control group: 25-54 yo Program applies to drivers <18 yo
Interventions	Jul 1998 (phase 1), Jan 1999 (phase 2) Level 1: min age 15,6 mos; min holding period 6 mos; supervision (eligible adult 21+ who sits in front seat); occupants <16 must wear safety belt; number of occupants does not exceed number of safety belts; no unsupervised driving 01:00-05:00 if under 17; driver's ed; 50 hrs supervised driving practice with 10 at night; must carry permit and ID

Ohio 2001 (*Continued*)

	while operating vehicle; Level 2: min age 16; if <17, no unsupervised driving 01:00-05:00 (exemptions apply); road test prior to level 2; number of occupants does not exceed number of safety belts; min age next stage 18 At both stages, lower demerit thresholds apply; license can be cancelled if convicted of certain traffic-related violations; license can be cancelled or revoked if convicted of any alcohol-related offence, including consumption or purchase Drivers <21 in Ohio cannot drive with >= 0.02% BAC Program information from: www.state.oh.us/odps/division/bmv/2f9.pdf
Outcomes	Driver involvement in all crashes (as reported by law enforcement) Fatal crashes Injury crashes Property damage only Convictions Suspensions Alcohol-related crashes Crashes by time of day Subgroup analyses for sex, and "at-fault" and "involved" crashes
Notes	Ohio

Raymond 2007

Methods	Controlled before-after: outcomes measure before and after the intervention and an appropriate control group was used Years studied: Mar 1999-July 2003
Participants	Age studied: 16-17 yo Control group: 25-65 yo Program applies to drivers <18 yo
Interventions	March 2000 Level 1: minimum of 6 mo, 50 hrs of supervised driving, complete an approved driver education course or certify an additional 50 hs of supervised driving Level 2: minimum of 12 mo, first 6mo with no passengers <20 who are not immediate family members unless driving with a driving instruction or a licensed parent/step-parent, no driving between 00:00-05:00 unless driving between home and work, home and school with no other ava liable transportation, employment purposes or accompanied by a driver > 24 yo for the first year Level 3: 18 yo
Outcomes	Crashes Suspensions Convictions
Notes	Oregon

Rice 2004

Methods	Controlled before-after: outcomes measure before and after the intervention and an appropriate control group was used Years studied: 1997 and 2000-2001
Participants	Age studied: 16-17 yo Control group:25-35 yo Program applies to drivers <18 yo
Interventions	July 1998 Level 1: aged 15.5 to 17 yo who completed a 30 hour drivers education course and 6 hours of on-road driving instruction, can drive under the supervision of a parent, guardian, or other adult aged 25 or older who holds a valid license and adult must document at least 50 hours of driving and 10 must be done after dark. Level 1 lasts for at least 6 months Level 2: no night-time driving between 00:00-5:00 unless accompanied and supervised by a parent, guardian, or other adult 25 or older who holds a valid drivers license for 12 months, no passengers under the age 20 unless a family members or accompanied by a licensed adult for the first 6 months. Level 2 lasts for at least 12 months or until 18 yo
Outcomes	Fatal and severe crashes Restricted or not restricted time crashes Multiple vehicle crashes Struck object crashes Struck pedestrian or bicycle crashes Non-collision crashes Culpable or non culpable crashes
Notes	California This is one of the secondary studies along with Masten 2004, Smith 2001, and Chaudhary 2007 (California only); the primary study is Males 2007

Rios 2006

Methods	Controlled before-after: outcomes measure before and after the intervention and an appropriate control group was used Years studied: 1992-2002
Participants	Age studied: Control group: Alabama, South Carolina, Tennessee Program applies to 15-18 yo
Interventions	July 1997 (strengthened in 2001: 16-17 yo could not drive between 00:00-06:00, passenger must be a family member for the first 6 months of provisional stage) Level 1:at least 15 yo and level 1 lasts for 12 months, complete drivers education and 20 hours of supervised driving (6 hours at night) or 40 hours of supervised driving (6 hours at night)and not convicted of any major traffic violation Level 2: at least 16 yo and level 2 lasts until 18 yo, cannot drive between 00:00-05:00 (extended to 06:00 in 2001), no driving with more than 3 passengers younger than 21 yo who were not the driver's immediate family (strengthened to only family member passengers for the first 6 months in 2001) and not convicted of any major traffic violations

Rios 2006 (*Continued*)

Outcomes	Fatal crashes Speed related fatal crashes
Notes	Georgia

Shope 2001

Methods	Ecological design: single group studied over time Years studied: 1996 versus 1998, 1999
Participants	Age group studied: 16 yo Control group: 25+ yo Program applies to drivers <18 yo
Interventions	Apr 1997 Level 1: min age 14,9 mos; min holding period 6 mos; must complete driver's ed to obtain level 1; supervision by licensed parent/guardian or designated adult (21+); must meet health standards; vision test; parent approval required; Level 2: min age 16; min holding period 6 mos; second segment of driver's ed required to advance to level 2; violation/crash-free for 90 days to graduate to level 2; road skills test prior to level 2; must complete 50 hours of supervised driving (including 10 at night) prior to level 2; no unsupervised driving 00:00-05:00; parental approval required for level 2; violation/crash-free for 12 mos to graduate to level 3; min age next stage 17. Parents can request a delay at either level. Zero tolerance law implemented in 1994: any alcohol involvement by teens can result in loss of license
Outcomes	All crashes (reported to local or state police agencies; reported if personal injury or >= $400 damage) Fatal crashes Non-fatal injuries All injuries (fatal and non-fatal) Daytime (05:00-20:59), evening (21:00-23:59), night-time crashes (00:00-04:59) Single and multiple vehicle crashes Alcohol-related crashes ("had been drinking" indicated on police report)
Notes	Michigan This is the secondary study and Shope 2004 is the primary study

Shope 2004

Methods	Ecological design: single group studied over time Years studied: 1994-1996 and 1998-2001
Participants	Age group studied: 16 yo
Interventions	Apr 1997 Level 1: min age 14,9 mos; min holding period 6 mos; must complete driver's ed to obtain level 1; supervision by licensed parent/guardian or designated adult (21+); must meet health standards; vision test; parent approval required; Level 2: min age 16; min holding period 6 mos; second segment of driver's ed required to advance to level 2; violation/crash-free for 90 days to graduate to level 2; road skills test prior to level 2; must complete 50 hours of supervised

Shope 2004 (*Continued*)

	driving (including 10 at night) prior to level 2; no unsupervised driving 00:00-05:00; parental approval required for level 2; violation/crash-free for 12 mos to graduate to level 3; min age next stage 17 Parents can request a delay at either level Zero tolerance law implemented in 1994: any alcohol involvement by teens can result in loss of license
Outcomes	All crashes Fatal crashes Non-fatal injury crashes Day crashes (05:00-21:00) Evening crashes (21:00-00:00) Night-time crashes (00:00-05:00) Single and multi-vehicle crashes One-passenger, two-passenger, three-or-more passengers
Notes	Michigan This is the primary study and Shope 2001 is the secondary study

Smith 2001

Methods	Ecological design: single group studied over time Years studied: 1999 and 2000 vs 1997
Participants	Age group studied: 16 yo No control groups Program applies to drivers under 18
Interventions	July 1998 level 1: min age 15, 6 mos; min holding period 6 mos; 50 hours supervised driving with 10 at night prior to level 2; driver ed; road test prior to level 2; Level 2: min age 16; no passengers <20 yo for first 6 mos unless supervised by licensed driver >25 yo; no unsupervised driving 00:00-05:00 for first 12 mos; min age next stage 18 Violation of GDL requirements punishable by 6-month suspension of driving privileges and possible fines or community service Program information from report and personal communication with author (Smith)
Outcomes	All driver-involved crashes resulting in injury Teen (15-19 yo) passengers injured while riding with 16 yo Night-time crashes (00:00-05:00)
Notes	California (San Diego County) This is one of the secondary studies along with Masten 2004, Rice 2004, and Chaudhary 2007 (California only); the primary study is Males 2007

Ulmer 2000

Methods	Ecological design: multiple groups studied over time Years studied: 1997 versus 1995
Participants	Age groups studied: 15, 16, and 17 yo (primary focus); 18 year olds (secondary) Control groups: 25-54 yo, external jurisdiction (Alabama) Program applies to drivers 15-17 yo
Interventions	Jul 1996 Level 1: min age 15; min holding period 6 mos; no driving 19:00-06:00 first 3 mos; no driving 22:00-06:00 after first 3 mos; lower demerit limit; Level 2: min age 16; min holding period 6 mos; no unsupervised driving 23:00-06:00 (16 yo), 01:00-05:00 (17 yo) ; lower demerit limit; min age next stage 18 Zero tolerance law implemented in Jan 1997: drivers <21 prohibited from driving with BAC of >= 0.02%
Outcomes	Driver involvements in fatal/injury crashes (police reported crashes excluding PDO) Subgroup analyses examined gender, white/nonwhite, urban/rural, day/night (23:00-06:00), and geographic regions within Florida
Notes	Florida

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

Study	Reason for exclusion
Cooper 2005	No data reported
Ferguson 1996	Comparison of licensing laws in several states; no comparison with GDLS
Hagge 1986	Evaluation of a provisional licensing program with only two stages
Hedlund 2003	Not primary research
Jones 1994	Evaluation of a provisional licensing program with only two stages
Mayhew 2006	Compared two GDL programs but no control (no GDL) comparison
Ross 2008	Not primary research
Teen Driver Crashes 2008	Not primary research
Teigan 2007	Not primary research
Ulmer 2001	Evaluation of only the first phase of graduated licensing
Williams 2009	Not primary research

(*Continued*)

You Can Hear a Pin Drop	Not primary research

DATA AND ANALYSES

This review has no analyses.

ADDITIONAL TABLES

Table 1. Description of GDLS at the time of the study*

Study	Jurisdiction	Min. age (initial)	Min. holding period	Min. age (interm)	Min. holding period	Night curfew	Passengers	Min. age (full)	IIHS rating
Morrisey 2006	48 US states Unable to get specific detail for each state	-	-	-	-	-	-	-	-
Dee 2005	48 US states Unable to get specific detail for each state	-	-	-	-	-	-	-	-
Baker 2006	43 US states Unable to get specific detail for each state	-	-	-	-	-	-	-	-
Chen 2006	43 US states Unable to get specific detail for each state	-	-	-	-	-	-	-	-
Chaudry 2007	California, Virginia, Massachusetts	C: 15,6 mos M: 16 V: 15,6 mos	C: 6 mos M: 6 mos V: 9 mos	C: 16 M: 16,6 mos V: 16,3 mos	C: 6 mos or until 17 M: 6 mos V: NR	C: 00:00-05:00 until 16,6 mos M: 00:00-05:00 V: 00:00-04:00	C: no passengers <20 unless supervised by a driver >24 for 6 mos or until driver is 17 M: no pas-	C: 17 M: 17 V: NR	C:good V:good M:good

Table 1. Description of GDLS at the time of the study* (*Continued*)

							sengers younger than 18 for the first 12 mos V: only one passenger <18 during the first 12 mos		
Males 2007	California	NR	6 mos	over 16	12 mos or 18	23:00-05:00	first 12 mos: no passengers younger than 20 (limited exception for immediate family)	18	good
Masten 2004	California	NR	6 mos	NR	12 mos	00:00-05:00	no passengers under 20 for 6 mos	NR	good
Rice 2004	California	15,6 mos	6 mos	17	12 mos	00:00-05:00	first 6 months: no passengers younger than 20 (limited exception for immediate family or if supervised)	18	good
Smith 2001	California (San Diego county)	15,6 mos	6 mos	16	NR	00:00-05:00 (during first 12 months)	no passengers <20 unless supervised by authorized, licensed driver >25	18	fair

Table 1. Description of GDLS at the time of the study* (*Continued*)

							during first 6 mos of provisional license		
Kingman 2008	New Zealand	15	6 mos	NR	12 mos with driver's ed	22:00-05:00	no passengers unless supervised	NR	marginal
Langley 1996	New Zealand	15	6 mos (3 mos with driver's ed)	15,3 mos	18 mos (9 mos with driver's ed)	22:00-05:00	no passengers unless supervised	16	marginal
Frith 1992	New Zealand	15	6 mos (3 mos with driver's ed)	15,3 mos	18 mos (9 mos with driver's ed)	22:00-05:00	no passengers unless supervised	16	marginal
Hallmark 2008	Iowa	14	6 mos	16	12 mos	00:30-05:00	passengers limited to number of seatbelts	17	fair
Neyens 2008	Iowa	NR	NR	16	12 mos	00:30-05:00	passengers limited to number of seatbelts	17	fair
Kellerman 2007	Georgia	15	12 mos	16	12 mos	00:00-05:00	First 6 mos: passengers must be immediate family After 6 mos: only 3 passengers <21 who are not immediate family	17	good
Rios 2006	Georgia	15	12 mos	16	until 18	00:00-06:00	no driving with more than 3 passengers younger than 21	18	good

Table 1. Description of GDLS at the time of the study* (*Continued*)

							who wee not the driver's immediate family (strengthened to only family member passengers for the first 6 mos in 2001)		
Margolis 2007	North Carolina	15	12 mos	16	6 mos	21:00-05:00	-	16,6 mos	good
Foss 2001	North Carolina	15	12 mos	16	6 mos	21:00-05:00	-	16,6 mos	fair
Kirley 2008	Maryland	15,9 mos	4 mos	16,1 mos	18 mos	00:00-05:00	first 5 months: no passengers younger than 18	17,7 mos	good
McKnight 1983	Maryland	15, 9 mos	14 days	16	6 mos	01:00-06:00	-	16,6 mos	marginal
Shope 2004	Michigan	14, 9 mos	6 mos	16	6 mos	00:00-05:00	-	17	fair
Shope 2001a	Michigan	14, 9 mos	6 mos	16	6 mos	00:00-05:00	-	17	fair
Mayhew 2003	Nova Scotia	16	6 mos (3 mos with driver's ed)	16,3 mos	24 mos	00:00-05:00 (exemptions available)	-	18,3 mos	fair
Mayhew 2000	Nova Scotia	16	6 mos (3 mos with driver's ed)	16,3 mos	24 mos	00:00-05:00 (exemptions available)	-	18,3 mos	fair
Hyde 2005	Utah	NR	NR	NR	NR	00:00-05:00 for those <17	passengers < 21 only with	NR	good

Table 1. Description of GDLS at the time of the study* (*Continued*)

							an adult driver for the first 6 mos		
Raymond 2007	Oregon	NR	6 mos	NR	12 mos	00:00-05:00	first 6mo with no passengers <20 who are not immediate family members unless driving with a driving instruction or a licensed parent/stepparent	18	good
Agent 2001	Kentucky	16	6 mos	16,6 mos	-	-	-	18	marginal
Fohr 2005	Wisconsin	15,6 mos	6 mos	16	9 mos	00:00-05:00	passengers limited to 1 unrelated passenger less than 21	16,3 mos	good
O'Connor 2007	Deleware	15,10 mos	6 mos	16,4 mos	12 mos	22:00-06:00	maximum of 2 passengers	17,4 mos	good
Ohio 2001	Ohio	15,6 mos	6 mos	16	until age 18	01:00-05:00 (if <17 yo)	-	18	fair
Ulmer 2000	Florida	15	6 mos	16	6 mos	23:00-06:00 (16 yo); 01:00-05:00 (17 yo)	-	18	fair
Boase 1998	Ontario	16	12 mos (8 mos with driver's ed)	16,8 mos	12 mos	-	-	17,8 mos	marginal

Table 1. Description of GDLS at the time of the study* (*Continued*)

Bouchard 2000	Quebec	16	12 mos (8 mos with driver's ed)	16,8 mos	24 mos or until 25	-	-	18,8 mos	marginal
O'Connor 2000	South Australia	16	none	16,6 mos	12 mos	-	-	19	poor
* based on information provided in the written report NR: not reported									

Table 2. Study Quality

Study	Jurisdiction	Control groups	Statistical methods	No. years studied	Confounders Adjusted	Confounders Discuss
Agent 2001	Kentucky	internal control group (19 yo and >19)	no multivariable methods	3 years pre and 3 years post-intervention	number of licensed drivers	reduced exposure (delay in licensing and decrease in miles driven)
Baker 2006	43 US states	internal control group (20-29 yo drivers)	multivariable modelling (negative bionomial regression)	11 years (43 GDLs implemented at different times)	state: weather, traffic environment, regulations other than GDL, socioeconomic conditions year quarter: seasonal variable year: variation in fatal crash counts during the study period	delay in licensure, decreased driving time and distance, law enforcement
Boase 1998	Ontario	internal control group (general driving population)	no multivariable methods	1-2 years pre and post-intervention; selected analyses conducted for 1988-1996 (6 years pre	number of licensed novice drivers	

Table 2. Study Quality (*Continued*)

				and 2 years post-intervention)		
Bouchard 2000	Quebec	internal control group (18-24 yo with regular license)	no multivariable modelling	2 years pre and post-intervention (including year of implementation)	number of licensed drivers	changes in licensing rates; contamination of control group; other legislative changes
Chaudhary 2007	California, Massachusetts, Virginia	internal control group (35-49 yo) and external control groups (Arizona vs California; Conneticut vs Massachusetts; Maylaynd vs Virginia)	time-series analyses (ARIMA)	California - time series from 1995-2003 (program implemented July 1998) Massachusetts - time series from 1995-2003 (program implemented Nov 1998) Virginia - - time series from 1999-2003 (program implemented July 2001)	periodic, systematic fluctuations in crash rates (e.g.: introduction of passenger restrictions, number of weekends in a month), cohort effects, economic changes, and other external variables that may account for change in crash rates when the laws were introduced	
Chen 2006	43 US states	internal control group (20-29 yo with regular licence)	multivariable modelling (negative bionomial regression)	11 years (43 GDLs implemented at different times)	state: state-specific unmeasured variations that might affect fatal crash counts (e.g. : , weather, traffic environment, regulations other than GDL, socioeconomic conditions) year quarter: seasonal variations year: variation in fatal crash counts	decrease in licensure
Dee 2005	48 US states	internal control group (18-26 yo)	multivariable modelling (negative bionomial regression)	11 years (48 GDLs implemented at different times)	relevant age-specific population, driving under the influence laws, seat belt	

Table 2. Study Quality (*Continued*)

					laws, increase in rural interstate speed limit, state unemployment rate, administrative license revocation	
Fohr 2005	Wisconsin	internal control group (25-59 yo drivers)	multivariable induced exposure modelling	1 year pre and 2 years post-intervention	changes in driving habits	reduced exposure; safer driving habits
Foss 2001	North Carolina	internal control group (25-54 yo)	multivariable modelling (Poisson regression)	2 years pre and 1 year post-intervention	changes in population (per capita rates); number of licensed drivers	reduced exposure (delay or reduction in licensure, less driving, driving under safer conditions); increase in licensing prior to GDL; mixture of license levels in age cohort
Frith 1992	New Zealand	internal control group (25+)	no multivariable modelling	6 years pre and 4 years post-intervention	license status; changes in population (population-based rates)	reduced exposure (delay in licensure or distance driven); economic factors
Hallmark 2008	Iowa	internal control group (35-44 yo)	no multivariable modelling	4 years pre and 4 years post-intervention	factors outside of the treatment that affect crashes (changes in crash reporting form and the types of crashes that are required to be reported)	exposure among 15 yo holding a minor school license
Hyde 2005	Utah	no control groups	time-series analyses (ARIMA)	time series from 1996-2001 (program implemented July 1999)	decrease in licensure	reduced exposure (delay in licensure)
Kellermann 2007	Georgia	internal control group (21-24 yo) and exter-	no multivariable modelling	5.5 years pre and 5.5 years post-intervention	seat belt usage	

Table 2. Study Quality (*Continued*)

		nal control groups (Tennessee, Alabama, South Carolina)				
Kingman 2008	New Zealand	external control groups (England, Wales, Scotland)	no multivariable modelling	6.5 years pre and 14.5 years post-intervention	driving experience	
Kirley 2008	Maryland	internal control group (30-59 yo population and drivers)	multivariable modelling (Poisson regression)	3 years pre and 3 years post-intervention	temporal trends unrelated to GDL	delayed licensure
Langley 1996	New Zealand	internal control groups (25+; 2 non-traffic injury groups 15-19 yo - assaults, struck by or against)	time-series analyses (ARIMA)	time series from 1978-1992 (program implemented Aug 1, 1987)		reduced exposure through reductions in number of licensed drivers and reductions in population for the 15-19 and 20-24 age groups; economic changes (increased unemployment)
Males 2007	California	internal control groups (20-44 yo drivers)	time-series analyses (ARIMA)	time series from 1995-2005 (program implemented July, 1998)	historical factors (e.g., belt use, enforcement, mileage), change in licensing rates	
Margolis 2007	North Carolina	internal control group (25-54 yo drivers)	time-series analyses (ARIMA)	time series from 1996-2001 (program implemented Dec, 1997)	general trends, seasonality, changes in population (number of licensed drivers and behavior of licensed drivers)	
Masten 2004	Calfornia	internal control group (24-55 yo)	time-series analyses (ARIMA)	time series from 1994-2001 (program implemented June,	general trends, seasonality, time-related autocorre-	change in licensure, inadequate GDL enforcement

Table 2. Study Quality (*Continued*)

				1998)	lation	
Mayhew 2000	Nova Scotia	internal (25+) and external (NB, SK, ME) control groups	time-series analyses (ARIMA)	rate comparisons: 1 year pre and 1-2 years post intervention; time series from 1986-1997 (program implemented Oct 1994)	changes in population; changes in licensing rates (for all novice drivers, not just teens)	change in reporting definition for PDO crashes in June 1995 from $500 to $1000; analyses showed that there was no significant change in reporting trend after June 1995
Mayhew 2003	Nova Scotia	no control groups	no multivariable modelling	2 years, 9 months pre and 2 years, 3 months post-intervention	changes in licensing rates	
McKnight 1983	Maryland	internal (18-21 yo) and external (Virginia and national) control groups	time-series analyses (ARIMA)	time series from 1975-1982 (program implemented Jan 1979)		changes in crash reporting; amount of travel and conditions under which travel occurs; oil crisis with resulting fuel shortage; tightening economy with increased unemployment; decrease in population and number of licenses issued
Morrisey 2006	48 US states	no control groups	multivariable modelling (negative bionomial regression)	11 years (48 GDLs implemented at different times)	driving under the influence laws, seat belt laws, increase in rural interstate speed limit, state unemployment rate, other motor vehicle laws that vary within states over time, na-	

Table 2. Study Quality (*Continued*)

					tional trends in crash fatalities	
Neyens 2008	Iowa	internal control groups (18 yo and 24-54 yo)	time-series analyses (ARIMA)	time series from 1995 to 2005 (program implemented Jan 1999)	seasonal trends, factors associated with the intervention	delay in licensure, transitional effect of GDL (more than one intervention point due to early educational campaigns or process changeovers), some drivers not in GDL but analysed as part of GDL
O'Connor 2000	South Australia	internal (older drivers) and external (province of Victoria)	time-series analyses (regression)	time series from 1983-1992 (program implemented Nov 1989)	changes in population	changes in licensing requirements within jurisdiction and for external comparison group; changes in licensing rates
O'Conner 2007	Deleware	no control groups	no multivariable modelling	1 year pre and 3 years post-intervention		secular trends (e.g. increased seat belt use and air bags), GDL enforcement, change in reporting definition for PDO crashes(1998: $1200; 1999: $1300; 2000: $1400; 2000-2001: $1500)
Ohio 2001	Ohio	internal control group (25-54 yo)	no multivariable modelling	primary comparisons made for drivers 2 years pre and 14 months post-intervention; data presented for 1988-1999 (pro-	changes in population; number of licensed drivers	

Table 2. Study Quality (*Continued*)

				gram implemented in 2 stages (Jul 1998, Jan 1999)		
Raymond 2007	Oregon	internal control group (25-65 yo)	no multivariable modelling	1 year pre and 3. 25 years post-intervention		miles driven
Rice 2004	California	internal control group (25-34 yo)	no multivariable modelling	1 year pre and 2 years post-intervention	overall crash trends	
Rios 2006	Georgia	external control group (Tennesse, Alabama, South Carolina)	multivariable modelling (Poisson regression)	5.5 years pre and 5.5 years post-intervention	historical effects	safety belt use, delay in licensure
Shope 2001a	Michigan	internal control group (25+)	no multivariable modelling	1 year pre and 2 years post-intervention	changes in population	delayed licensure
Shope 2004	Michegan	internal control group (25+)	no multivariable modelling	3 years pre and 4 years post-intervention	changes in population	delayed licensure, parental restrictions in addition to GDL
Smith 2001	California	no control groups	no multivariable methods	1 year pre and 2 years post-intervention	number of licensed drivers (rates per licensed drivers), population changes (per capita crash rates)	reduced exposure (changes in licensing rates)
Ulmer 2000	Florida	internal (25-54 yo) and external (Alabama) control groups	no multivariable methods	1 year pre and 1 year post-intervention	changes in population	licensing rate (increased over study period)

Table 3. Overall Crashes: 16 year old drivers

Study	Jurisdiction	Denominator	Baseline rate*	Unadj % change yr 1	Adj % change yr 1	Unadj % chge last yr	Adj % change last yr	Yrs studied post-GDL

Table 3. Overall Crashes: 16 year old drivers (*Continued*)

Foss 2001	North Carolina	population	1,181	-28	-29	-	-	-
Mayhew 2000	Nova Scotia	population	387	-34	-21	-	-	-
Mayhew 2003	Nova Scotia	population	749	-29	-	-	-	1
McKnight 1983	Maryland	population	823	-41	-8	-45	-8	3
Kirley 2008	Maryland	population	509	-14	-	-14	-	3
Shope 2001a	Michigan	population	1,540	-26	-20	-28	-24	2
Shope 2004	Michigan	population	1590	-26	-	-30	-	4
Chaudhary 2007	California	population	-	-	-	-	-13	5
Chaudhary 2007	Massachussets	population	-	-	-	-	-21	5
Chaudhary 2007	Virginia	population	-	-	-	-	-27	2
Fohr 2005	Wisconsin	population	1125	-17	-11	-19	-13	2
Raymond 2007	Oregon	population	840	-13	-6	-29	-18	3
Agent 2001	Kentucky	licensed drivers	1,910	-31	-36	-35	-34	3
Boase 1998	Ontario	licensed drivers	1,227	-79	-73	-83	-74	2
Foss 2001	North Carolina	licensed drivers	1,757**	-19	-	-	-	-
Hallmark 2008	Iowa	licensed drivers	1820	-	-	-30	-8	4
Neyens 2008	Iowa	licensed drivers	1620	7	27	-22	11	6

Table 3. Overall Crashes: 16 year old drivers (*Continued*)

Hyde 2005	Utah	licensed drivers	1366	-1	*	-5	96 less crashes per year per 10000 drivers	2
Kirley 2008	Maryland	licensed drivers	1511	+11	-	+15	-	3
O'Connor 2007	Deleware	licensed drivers	1660	-	-	-28	-	3
* per 10,000 persons								
** averaged over 2 year period								

Table 4. Overall Crashes: all teenage drivers

Study	Jurisdiction	Age group	Denominator	Baseline rate*	Unadj % change yr 1	Adj % change yr 1	Unadj % chge last yr	Adj % change last yr	Yrs studied post-GDL
Mayhew 2000	Nova Scotia	16-17	population	440	-20	-7	-	-	-
Mayhew 2003	Nova Scotia	16-19 novices	population	690	-28	-	-	1	-
Chaudhary 2007	California	15-17	population	-	-	-	-	not significant	5
Chaudhary 2007	Massachusetts	15-17	population	-	-	-	-	-16	5
Chaudhary 2007	Virginia	15-17	population	-	-	-	-	-13	2
Fohr 2005	Wisconsin	16-18	population	1142	-10	-4	-13	-6	2
Hallmark 2008	Iowa	14-17	licensed drivers	1112	-	-	-32	-11	4
Agent 2001	Kentucky	16-19	licensed drivers	1,850	-6	-11	-5	-4	3

Table 4. Overall Crashes: all teenage drivers (*Continued*)

Boase 1998	Ontario	16-19	licensed drivers	897	-25	-19	-36	-27	2
Boase 1998	Ontario	16-19 novices	licensed drivers	1,362	-31	-	-	-	2
* per 10,000 persons									

Table 5. Injury Crashes: 16 year old drivers

Study	Jurisdiction	Denominator	Baseline rate*	Unadj % change yr 1	Adj % change yr 1	Unadj % chge last yr	Adj % change last yr	Yrs studied post-GDL
Foss 2001	North Carolina	population	45	-36	-34	-	-	-
Frith 1992	New Zealand	population	83	-43	-41	-35	-33	4
Mayhew 2000	Nova Scotia	population	131	-34	-34	-	-	-
McKnight 1983	Maryland	population	261	-16	-6	-14	-2	3
Shope 2001a	Michigan	population	437	-28	-21	-33	-21	2
Shope 2004	Michigan	population	448	-27	-	-33	-	4
Smith 2001	California	population	118	-4	-	-19	-	2
Chaudhary 2007	California	population	-	-	-	-	0.13 per 1000 less	5
Rice 2004	California	population	116	-21	-	-21	-	3
Masten 2004	California	population	134	-23	-35	-32	-46	2
Ulmer 2000	Florida	population	323	-10	-11	-	-	-
Chaudhary 2007	Massachusetts	population	-	-	-	-	0.16 per 1000 less	5

Table 5. Injury Crashes: 16 year old drivers (*Continued*)

Chaudhary 2007	Virginia	population	-	-	-	-	0.44 per 1000 less	2
Fohr 2005	Wisconsin	population	401	-23	-15	-24	-16	2
Agent 2001	Kentucky	licensed drivers	621	-35	-	-39	-	3
Smith 2001	California	licensed drivers	475	+3	-	-0.6	-	2
O'Connor 2007	Deleware	licensed drivers	360	-	-	-33	-	3
* per 10,000 persons								

Table 6. Injury Crashes: all teenage drivers

Study	Jurisdiction	Age group	Denominator	Baseline rate*	Unadj % change yr 1	Adj % change yr 1	Unadj % chge last yr	Adj % change last yr	Yrs studied post-GDL
Frith 1992	New Zealand	15-19	population	102	-25	-23	-22	-20	4
Mayhew 2000	Nova Scotia	16-17	population	141	-14	-14	-	-	-
Ulmer 2000	Florida	15-17	population	257	-8	-9	-	-	-
Chaudhary 2007	California	15-17	population	-	-	-	-	0.14 per 1000 less	5
Masten 2004	California	15-17	population	108	-10	-22	-22	-36	2
Chaudhary 2007	Massachusetts	15-17	population	-	-	-	-	-0.13 per 1000 less	5
Chaudhary 2007	Virginia	15-17	population	-	-	-	-	-0.21 per 1000 less	2
Fohr 2005	Wisconsin	16-18	population	162	-13	-4	-18	-7	2
Agent 2001	Kentucky	16-19	licensed drivers	581	-11	-	-13	-	3

Table 6. Injury Crashes: all teenage drivers (*Continued*)

Boase 1998	Ontario	16-19 novices	licensed drivers	369	-27	-	-	-	-
Bouchard 2000	Quebec	learner & probationary drivers; number of victims	licensed drivers	619**	-14***	-17	-	-	-
* per 10,000 persons									
** averaged over 2 year period									
*** post-implementation rate averaged over 2 years									

Table 7. Hospitalizations: 16 year olds

Study	Jurisdiction	Denominator	Baseline rate*	Unadj % change yr 1	Adj % change yr 1	Unadj % chge last yr	Adj % change last yr	Yrs studied post-GDL
Langley 1996	New Zealand	population	41	-41	-35	-44	-28	5
Langley 1996	New Zealand	licensed drivers	100	-27	-	-15	-	5
Margolis 2007	North Carolina	licensed drivers	unknown	-	-	-	-37	4
O'Connor 2007	Deleware	licensed drivers	20	-	-	-41	-	3
* per 10,000 persons								

Table 8. Hospitalizations: all teenagers

Study	Jurisdiction	Age groups	Denominator	Baseline rate*	Unadj % change yr 1	Adj % change yr 1	Unadj % chge last yr	Adj % change last yr	Yrs studied post-GDL
Frith 1992	New Zealand	15-19; just drivers	population	19	-32	-28	-37	-31	2
Langley 1996	New Zealand	15-19	population	42	-26	-20	-36	-20	5
O'Connor 2000	South Australia	16-19; just drivers	population	22	-23	-19	-50	-26	3
Langley 1996	New Zealand	15-19	licensed drivers	84	-18	-	-25	-	5
* per 10,000 persons									

Table 9. Fatal Crashes: 16 year old drivers

Study	Jurisdiction	Denominator	Baseline rate*	Unadj % change yr 1	Adj % change yr 1	Unadj % chge last yr	Adj % change last yr	Yrs studied post-GDL
Foss 2001	North Carolina	population	5.0	-60	-	-	-	-
Shope 2001a	Michigan	population	3.7	-24	-19	-32	-22	2
Shope 2004	Michigan	population	3.8	-24	-	-11	-	4
McKnight 1983	Maryland	population	2.2	+56	+56	-8	-1	3
Kirley 2008	Maryland	population	3.4	-32	-	-32	-	3
Kellerman 2007	Georgia	population	31.7	-	-	-37	-25	5.5
Rios 2006	Georgia	population	6	-42	-57	-38	-15	5
Males 2007	California	population	0.46	-	-	-14	-14	6
Rice 2004	California	population	7.2	-37	-	-27	-	3

Table 9. Fatal Crashes: 16 year old drivers (*Continued*)

Chen 2005	USA (43 states)	population	-	-	-	-	-11	variable
Kingham 2007	New Zealand	population	4.8	-60	-160	-38	-110	14
Agent 2001	Kentucky	licensed drivers	12.4	-43	-	-53	-	3
Boase 1998	Ontario	licensed drivers	6.6	-73	-59	-76	-55	2
Baker 2006	USA (43 states)	licensed drivers	2.5	-	-	-	-11	variable
Kirley 2008	Maryland	licensed drivers	10.1	-14	-	-9	-	3
O'Connor 2007	Deleware	licensed drivers	4.9	-	-	-50	-	3
* per 10,000 persons								

Table 10. Fatal Crashes: all teenage drivers

Study	Jurisdiction	Age Group	Denominator	Baseline rate*	Unadj % change yr 1	Adj % change yr 1	Unadj % chge last yr	Adj % change last yr	Yrs studied post-GDL
Frith 1992	New Zealand	15-19; number of fatalities	population	6.0**	-15	-	-	-	-
Kingham 2007	New Zealand	15-19	population	2.8	-10	-57	-52	-45	14
O'Connor 2000	South Australia	16-19; number of driver fatalities	population	1.3	-23	-15	-64	-47	3
Males 2007	California	16-19	population	0.93	-	-	-4	2	6
Kellerman 2007	Georgia	16-19	population	31.9	-	-	-16	-16	5.5

Table 10. Fatal Crashes: all teenage drivers (*Continued*)

Dee 2005	USA (48 states)	15-17	population	-	-	-	-5.6 to -9.8	-	10
Boase 1998	Ontario	16-19	licensed drivers	3.3	-33	-19	-39	-18	2
Boase 1998	Ontario	16-19 novices	licensed drivers	3.5	-20	-	-	-	-
Bouchard 2000	Quebec	learners & probationary drivers; number of fatalities	licensed drivers	8.2***	-26****	-6	-	-	-
Morrisey 2006	USA (43 states)	15-17		-	-	-	-7	-	variable
* per 10,000 persons									
** averaged over 3.5 year period									
*** averaged over 2 year period									
**** post-implementation rate averaged over 2 years									

Table 11. Nighttime crashes: 16 year old drivers

Study	Jurisdiction	Denominator	Baseline rate*	Unadj % change yr 1	Adj % change yr 1	Unadj % chge last yr	Adj % change last yr	Yrs studied post-GDL
Foss 2001**	North Carolina	population	165	-47	-	-	-	-
Shope 2001a***	Michigan	population	63	-46	-37	-57	-51	2

Table 11. Nighttime crashes: 16 year old drivers (*Continued*)

Shope 2004***	Michigan	population	48	-40		-58		4
Smith 2001***	California	population	4	-25	-	-50	-	2
Mayhew 2003***	Nova Scotia	population	40	-50		-64		2
Agent 2001****	Kentucky	licensed drivers	80	-33	-	-42	-	3
Smith 2001***	California	licensed drivers	15	-20	-	-33	-	2
Hyde 2005***	Utah	licensed drivers	36	6				2
O'Conner 2007**	Deleware	licensed drivers	357			-43		3
* per 10,000 persons								
** night curfew began before midnight								
*** night curfew began at midnight								
**** night curfew during initial, rather than intermediate, stage of licensure								

Table 12. Nighttime crashes: all teenage drivers

Study	Jurisdiction	Age Group	Denominator	Baseline rate*	Unadj % change yr 1	Adj % change yr 1	Unadj % chge last yr	Adj % change last yr	Yrs studied post-GDL
Agent 2001**	Kentucky	16-19	licensed drivers	109	-3	-	-14	-	3
Boase1998**	Ontario	16-19 novices	licensed drivers	103	-48	-	-	-	-
Frith 1992***	New Zealand	15-19	licensed drivers	-	-32	-	-	-	-
* per 10,000 persons									
** night curfew during initial, rather than intermediate, stage of licensure									
*** night curfew began before midnight									

Table 13. Alcohol crashes: 16 year old drivers

Study	Jurisdiction	Denominator	Baseline rate*	Unadj % change yr 1	Adj % change yr 1	Unadj % chge last yr	Adj % change last yr	Yrs studied post-GDL
Foss 2001**	North Carolina	population	8	-38	-	-	-	-
Shope 2001a**	Michigan	population	10	-16	-2	-17	+3	2
Agent 2001***	Kentucky	licensed drivers	33	-39	-	-42	-	3
* per 10,000 persons								

Table 13. Alcohol crashes: 16 year old drivers (*Continued*)

** zero BAC								
*** 0.02 mg/dl								

Table 14. Alcohol crashes: all teenage drivers

Study	Jurisdiction	Age group	Denominator	Baseline rates*	Unadj % change yr 1	Adj % change yr 1	Unadj % chge last yr	Adj % change last yr	Yrs studied post-GDL
Agent 2001**	Kentucky	16-19	licensed drivers	39	+15	-	-4	-	3
Boase 1998***	Ontario	16-19 novices	licensed drivers	23	-19	-	-	-	-
Bouchard 2000***	Quebec	learner & probationary drivers; number of ...	licensed drivers	73****	-12*****	-9	-	-	-
Frith 1992**	New Zealand	15-19	licensed drivers	-	-23	-	-	-	-
* per 10,000 persons									
** 0.02 mg/dl (Agent); 0.03 mg/dl (Frith)									
*** zero BAC									
**** averaged over 2 year period									
***** post-implementation rate averaged over 2									

Table 14. Alcohol crashes: all teenage drivers (*Continued*)

years									

Table 15. Results from Multivariate Modeling

Study	Model	Control Group	Results
Chaudhary 2007	ARIMA	CA: Arizona; 18-19 and 35-49 yo drivers MA: Connecticut; ages? VA: Maryland; 18-19 and 35-49 yo drivers	Crashes: CA: 0.13 fewer crashes/1000 16 yo/ month (p=0.03) or 13% reduction No significant reduction among 15-17 yo drivers MA: 0.16 fewer crashes/1000 16 yo/ month (<0.01) or 16% reduction 0.13 fewer crashes/1000 15-7 yo/ month Decrease among 18-19 yo (not affected by GDL) VA: 0.38 fewer crashes/1000 16 yo/ month (p=0.02) or 38% reduction (454 fewer crashes) 0.18 fewer crashes/1000 15-7 yo/ month
Hyde 2005	ARIMA	No Decreasing trend in 16 year-old driver crashes	Crashes: 0.8 fewer crashes/month/1,000 licensed drivers 9.6 fewer crashes/ 1,000 licensed 16 yo/ year
Langley 1996	ARIMA	≥25 yo drivers	Hospitalized crashes: 23% reduction among 15-19 yo 7% net reduction (16% reduction in ? 25 yo drivers)
Males 2007	ARIMA	20-44 yo drivers	Fatalities: 20% reduction among 16 yo drivers (p= 0.07) 24% increase among 18 yo drivers (p= 0.01)
Margolis 2007	ARIMA	25-54 yo drivers	Hospitalized crashes: 37% reduction in the rate/population among 16 yo (p<0.05) 12% reduction in the rate/population among 17 yo (p>0.05)

Table 15. Results from Multivariate Modeling (*Continued*)

Masten 2004	ARIMA	24-54 yo drivers	Injury and fatal crashes: No overall reduction among 15-17 yo or 16 yo Nighttime crashes: 55 fewer injury/fatal crashes/yr among 16-17 yo Passenger restrictions: 816 fewer injury/fatal crashes/yr among 16-17 yo
Mayhew 2000	ARIMA	≥25 yo drivers and external control group	Crashes: 7 fewer crashes/mo for 16yo ($p<0.05$)
McKnight 1983	ARIMA	18-21 yo drivers National data, Virginia	Daytime crashes: 5% reduction ($p=0.08$)
Neyens 2008	ARIMA	25-54 yo drivers Virginia	Crashes: 5.6 fewer crashes/10,000 licensed 16yo drivers/month or 243 crashes/yr Significant reduction among 17 yo drivers but not for 18yo drivers
Rios 2006	Poisson regression		Fatal crashes 16 yo RR: 0.63; 95% CI 0.53, 0.75 17 yo RR: 0.81; 95% CI 0.69, 0.95
Kirley 2008	Poisson regression	30-59 yo drivers	Crashes Population RR: 0.82; 95% CI: 0.71, 0. 96 Licensed driver RR: RR: 1.09; 95% CI: 0.93, 1.27 Injury crashes Population RR: RR: 0.63; 95% CI: 0. 41, 0.98 Licensed driver RR: RR: 0.83; 95% CI: 0.52, 1.32
Foss 2001	Poisson regression	25-54 yo drivers	Crashes 16 yo RR: 0.73; 95% CI: 0.71-0.75 Fatal crashes 16 yo RR: 0.43; 95% CI: 0.27, 0.70 Injury crashes 16 yo RR: 0.72; 95% CI: 0.62, 0.84 Nighttime restrictions 16 yo RR: 0.57; 95%CI: 0.52, 0.61
Baker 2006	Negative binomial regression	20-29 yo drivers	Fatal crashes 16 yo IRR: 0.89; 95% CI: 0.80, 0.99

Table 15. Results from Multivariate Modeling (*Continued*)

			No reduction in older age groups Significant reduction only in programs with 5 of 7 components IRR for minimum holding period ?3 mo in the learning stage, nighttime, and passenger restrictions: 0.79; 95% CI: 0. 66, 0.94 IRR for minimum holding period of at ≥3 mo in the learners stage, night-time and passenger restrictions, and ?30 hours of supervised driving: 0.84; 95% CI: 0.74, 0.96
Chen 2006	Negative binomial regression	20-29 yo drivers	Same as Baker 2006
Dee 2005	Negative binomial regression	18-26 yo drivers	Fatal crashes 9.8% reduction (p<0.01) IIHS 'good' rating: 19% reduction (p<0.01) IIHS 'fair' rating: 5.9% reduction (p< 0.05) IIHS 'marginal' rating: 4.6% reduction (p>0.05)
Morrisey 2006	Negative binomial regression		Fatal crashes ? rural? 6.5% reduction (p>0.05) IIHS 'good' rating: 30.5% reduction (p<0.05)
O'Conner 2000	Cut-point regression	≥20 yo drivers	Residual mean square was minimized for 1988 and 1989 (program Nov 1989) suggesting GDL was having a positive impact

APPENDICES

Appendix 1. Search strategy

set	search statement
1	((graduate$ or gradual$ or driver or provisional) adj (permit$ or licen$ or restrict$ or delay$ or accredit$ or certif$)).mp
2	gdl.ti,ab.
3	1 or 2
4	exp Automobile Driving/
5	limit 4 to adolescent <13 to 18 years>
6	3 or 5
7	exp adolescence/
8	(teen$ or youth or adolescen$).ti,ab.
9	((junior or senior or high or secondary) adj school$).ti,ab.
10	"young adult$".ti,ab.
11	or/7-10
12	4 and 11
13	or/3,6,12
14	limit 13 to yr=2001-2003

WHAT'S NEW

Last assessed as up-to-date: 13 October 2009.

Date	Event	Description
4 May 2011	New citation required and conclusions have changed	The review has been updated, with the inclusion of 21 new studies. The results and conclusions have been updated. The authors of the review have changed

HISTORY

Protocol first published: Issue 4, 2001

Review first published: Issue 2, 2004

Date	Event	Description
10 July 2008	Amended	Converted to new review format.

CONTRIBUTIONS OF AUTHORS

KR coordinated the update, contributed to searching, relevance and inclusion screening, assessment of study quality for the update, data extraction, data analysis, and writing the review.

BV conducted the statistical analysis and interpretation of data.

LH coordinated the original review, drafted the protocol and original review, and contributed to literature searching, relevance and inclusion screening, assessment of study quality for the original review, data extraction for the original study, data analysis and interpretation.

DECLARATIONS OF INTEREST

None known.

SOURCES OF SUPPORT

Internal sources

- Department of Public Health, Capital Health Authority, Edmonton, Alberta, Canada.
- Alberta Research Centre for Child Health Evidence, Edmonton, Alberta, Canada.

External sources

- Alberta Heritage Foundation for Medical Research, Canada.
- Population and Public Health, Alberta Health Services, Not specified.

INDEX TERMS

Medical Subject Headings (MeSH)

*Automobile Driving [legislation & jurisprudence; statistics & numerical data]; *Licensure [legislation & jurisprudence; standards]; Accidents, Traffic [*prevention & control; statistics & numerical data]; New Zealand; Ontario; Program Evaluation; United States

MeSH check words

Adolescent; Humans; Young Adult