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

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[Intervention Review]

Graduated driver licensing for reducing motor vehicle crashes among young drivers

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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 systems in reducing crash rates of young drivers.

Search strategy

Studies were identified through searches of MEDLINE, EMBASE, CINAHL, Healthstar, Web of Science, NTIS Bibliographic Database, TRIS Online, SIGLE, the World Wide Web, relevant conference proceedings, consultation with experts and authors, and reference lists. The search was not restricted by language or publication status.

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. Two reviewers independently screened searches and assessed the full text of potentially relevant studies for inclusion using a standard form.

Data collection and analysis

Data were extracted by one reviewer and checked by a second. Additional data were requested from authors. Results were not pooled due to substantial heterogeneity between studies. Percentage change was calculated for each year after the intervention, using one year prior to the intervention as the baseline rate. Results were adjusted by internal controls. Analyses were stratified by different denominators (population, licensed drivers). Results were calculated for the different crash types (overall, injury, fatal, night-time, alcohol, and those resulting in hospitalization). Results were presented for 16 year-olds alone and all teenage drivers combined.

Main results

We included 13 studies evaluating 12 GDL programs that were implemented between 1979 and 1998 in the US (n=7), Canada (3), New Zealand (1), and Australia (1). Programs varied in their restrictions during the intermediate stage: e.g. night curfews (8); limitations of extra passengers (2); roadway restrictions (1). Based on the Insurance Institute for Highway Safety classification scheme, no programs were good, six were acceptable, five were marginal, and one was poor. 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 overall crash rates during the first year was 31% (range 26-41%). Per population injury crash rates were similar (median 28%, range 4-43%). Results for all teenage drivers, rates per licensed driver, and rates adjusting for internal controls were generally reduced when comparing within jurisdictions.

Authors' conclusions

The existing evidence shows that GDL is effective in reducing the crash rates of young drivers, although the magnitude of the effect is unclear. The conclusions are supported by consistent direction of the findings, and the temporal relationship and plausibility of the association. The reviewers have made recommendations for primary research on GDL (e.g. study methods, standardized reporting of outcomes and results, long-term follow-up). The project has also shown what is needed to carry out systematic reviews of observational studies (e.g. quality assessment instruments).

PLAIN LANGUAGE SUMMARY

Graduated driver licensing effective in reducing crash rates of 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. Nevertheless, relatively little research has been done to see whether GDL actually works. This review found 13 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, from the evidence available, it is not possible to say which aspects of GDL programs have the biggest effect. The reviewers have made recommendations for further research on GDL.

BACKGROUND

It is well recognized that teenagers are more likely to be involved in motor vehicle crashes (MVCs) compared to older drivers (Foss 2000a). In Canada and the United States, crash rates per mile driven are three to ten times higher among teenage drivers than among older, more experienced drivers (Doherty 1998; Foss 2000a). MVCs account for 40% of fatalities from all causes among adolescents aged 16 to 19 years (Ferguson 1996). While overall motor vehicle death rates per licensed driver have decreased over the past two decades, those for teenagers (particularly 16 year-olds) in the US have actually increased (IIHS 1998). Teenage drivers represent not only a threat to themselves, but to other road users (Foss 1999).

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 skill 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 ad-

dress 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; almost all states and provinces have at least one of the key components of GDL (Williams 2003b). While the concept of GDL has become more accepted, there is limited empirical evidence to support their effectiveness. Most of the research that has been done has been directed at different components of GDL. 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 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 (Cochrane 2001). 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 on 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.

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.

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 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. 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),
- hospitalizations (hospital admissions due to crashes),
- fatality crashes (crashes involving fatal injuries),
- 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

The search is considered up to date as of October 2003.

Electronic searches

Initially, a core list of relevant studies was created using known review articles and their references. MEDLINE and EMBASE were searched based on the search strategy in Appendix 1. The initial searches from these two databases were compared against the core list to ensure that important studies were picked up, and to identify key words used to describe these studies. Using search terms relevant to each source, we also searched:

- CINAHL,
- Healthstar,
- Web of Science,
- NTIS Bibliographic Database (National Technical Information Service),
- TRIS Online (Transportation Research Information Service),
- SIGLE,
- and the World Wide Web:
  - Insurance Institute for Highway Safety-US;
  - National Highway Traffic Safety Administration-US;
  - Traffic Injury Research Foundation-Cda;
  - Land Transport Safety Authority-NZ;
  - Swedish National Road Administration;
  - Federal Office of Road Safety-Australia;
  - Transport Research Laboratory-UK.

Searching other resources

Primary authors of relevant studies and experts in the field were contacted. Proceedings from relevant conferences (ICADTS 1995, 2000) and a Symposium on GDL (Chatham MA, 2002) were examined. Finally, reference lists of all potentially eligible studies were examined for other relevant articles.

Data collection and analysis

Selection of studies

The selection of studies involved two steps. First, the initial search of all databases and reference lists was screened independently by two investigators (LH, KR) to identify citations with potential relevance. Second, the full text of selected articles was obtained. Two reviewers (LH, JP, or 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 (KR, NW) and checked by a second investigator (LH, KR, or NW). 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. Additional data were requested from the investigators of all studies.

Assessment of risk of bias in included studies

The assessment of quality for observational studies is problematic. 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, acceptable, marginal, 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.

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.

Two reviewers (LH, NW) independently assessed both study quality and program quality. Quality was assessed based on information provided in the written report. 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. 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.
Percent changes were either calculated directly from rates or from raw numbers. Some data were extracted from graphs (Foss 2001; Frith 1992; O'Connor 2000), or derived from other summary statistics (Shope 2001; Frith 1992; Smith 2001). Additional data came from authors (McKnight 1983; Agent 2001; Langley 1996) 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. Percent 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 three 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

Papers were screened for inclusion. Thirteen studies were deemed relevant for the review.

Included studies

Two studies evaluated GDL in the same jurisdiction (New Zealand). Both studies were included as they reported on different outcomes (injury crashes versus hospitalizations). Two studies were identified as papers in peer-reviewed medical journals (Langley 1996; Ulmer 2000). Eleven studies were identified through the grey literature: eight internal reports (Agent 2001; Boase 1998; Frith 1992; Foss 2001; Mayhew 2000; McKnight 1983; O'Connor 2000; Ohio 2001), two papers in conference proceedings (Bouchard 2000; Smith 2001), one abstract (Shope 2001). Two of the studies identified through the grey literature were subsequently published in peer-reviewed journals during the course of the review (Foss 2001; Shope 2001).

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 Insurance Institute for Highway Safety classification scheme and the information provided in the written reports, no programs were good, six were acceptable (Foss 2001; Mayhew 2000; Ohio 2001; Shope 2001; Smith 2001; Ulmer 2000), five were marginal (Agent 2001; Boase 1998; Bouchard 2000; Langley 1996/Frith 1992; McKnight 1983), and one was poor (O'Connor 2000). 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). Eight programs had a night driving restriction during the intermediate stage (Foss 2001; Langley 1996/Frith 1992; Mayhew 2000; McKnight 1983; Ohio 2001; Shope 2001; Smith 2001; Ulmer 2000). However, the night driving restriction began before midnight in only three of the programs (Foss 2001; Langley 1996/Frith 1992; Ulmer 2000) and lasted until at least age 17 in five programs (Mayhew 2000; Ohio 2001; Shope 2001; Smith 2001; Ulmer 2000). Only two programs had a passenger restriction during the intermediate stage (Langley 1996/Frith 1992; Smith 2001); the restriction could be lifted by age 16 in one jurisdiction (Langley 1996) and by 16.5 in the other (Smith 2001).

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

Study	Jurisdiction	Min. age (initial)	Min. holding period	Min. age (interm)	Min. holding period	Night curfew	Passengers	Min. age (full)	IIHS rating
Agent	Kentucky	16	6 mos	16,6 mos	-	-	-	18	marginal
Boase 1998	Ontario	16	12 mos (8 mos with driver's ed)	16,8 mos	12 mos	-	-	17,8 mos	marginal
Bouchard 2000	Quebec	16	12 mos (8 mos with driver's ed)	16,8 mos	24 mos or until 25	-	-	18,8 mos	marginal
Foss 2001	North Carolina	15	12 mos	16	6 mos	21:00-05:00	-	16,6 mos	acceptable
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
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
Mayhew 2000	Nova Scotia	16	6 mos (3 mos with driver's ed)	16,3 mos	24 mos	midnight-05:00 (exemptions available)	-	18,3 mos	acceptable
McKnight 1983	Maryland	15, 9 mos	14 days	16	6 mos	01:00-06:00	-	16,6 mos	marginal
O'Connor 2000	South Australia	16	none	16,6 mos	12 mos	-	-	19	poor
Ohio 2001	Ohio	15,6 mos	6 mos	16	until age 18	01:00-05:00 (if < 17 yo)	-	18	acceptable
Shope 2001a	Michigan	14, 9 mos	6 mos	16	6 mos	midnight-05:00	-	17	acceptable
Smith 2001	California (San Diego county)	15, 6 mos	6 mos	16		00:00-05:00 (during first 12 months)	no passengers <20 unless supervised by autho-	18	acceptable

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

							rized, licensed driver >25 years during first 6 mos of provisional license		
Ulmer 2000	Florida	15	6 mos	16	6 mos	23:00-06:00 (16 yo); 01:00-05:00 (17 yo)	-	18	acceptable
* based on information provided in the written report									

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).

Table 2. Study Quality

Study	Jurisdiction	Control groups	Statistical methods	No. years studied	Confounders Adjusted	Confounders Discuss
Agent	Kentucky	internal control group (19 year olds and >19)	no multivariable methods	3 years pre and post-intervention	number of licensed drivers	reduced exposure (delay in licensing and decrease in miles driven)
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 and 2 years post-intervention)	number of licensed novice drivers	

Table 2. Study Quality (*Continued*)

Bouchard 2000	Quebec	internal control group (18-24 yo with regular license)	no multivariable modeling	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
Foss 2001	North Carolina	internal control group (25-54)	multivariable modeling (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 modeling	6 years pre, 4 years post-intervention	license status; changes in population (population-based rates)	reduced exposure (delay in licensure or distance driven); economic factors
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)
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

Table 2. Study Quality (*Continued*)

McKnight 1983	Maryland	internal (18-21) 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
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
Ohio 2001	Ohio	internal control group (25-54)	no multivariable modeling	primary comparisons made for drivers 2 years pre and 14 months post-intervention; data presented for 1988-1999 (program implemented in 2 stages (Jul 1998, Jan 1999)	changes in population; number of licensed drivers	
Shope 2001a	Michigan	internal control group (25+)	no multivariable modeling	1 year pre and 2 years post-intervention	changes in population	delayed licensure
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	reduced exposure (changes in licensing rates)

Table 2. Study Quality (*Continued*)

					(per capita crash rates)	
Ulmer 2000	Florida	internal (25-54) and external (Alabama) control groups	no multivariable methods	1 year pre and post-intervention	changes in population	licensing rate (increased over study period)

Four studies used both internal and external control groups to control for factors beyond the GDL program that may have affected outcome (Mayhew 2000; McKnight 1983; O'Connor 2000; Ulmer 2000). Eight studies used internal control groups only (Agent 2001; Boase 1998; Bouchard 2000; Foss 2001; Frith 1992; Langley 1996; Ohio 2001; Shope 2001). One study had no control groups (Smith 2001).

Eight studies used no multivariable methods to control for confounding (Agent 2001; Boase 1998; Bouchard 2000; Frith 1992; Ohio 2001; Shope 2001; Smith 2001; Ulmer 2000), while three studies conducted ARIMA time series analyses (Langley 1996; Mayhew 2000; McKnight 1983) and one study performed multivariable modeling with Poisson regression (Foss 2001). 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.

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 (Foss 2001; Frith 1992; Mayhew 2000; O'Connor 2000; Ohio 2001; Shope 2001; Smith 2001; Ulmer 2000) and changes in licensing through the use of rates per licensed drivers (Agent 2001; Boase 1998; Bouchard 2000; Foss 2001; Mayhew 2000; Ohio 2001; Smith 2001). In addition, the majority of studies discussed other possible confounders and their potential impact on outcome (Table 03). These included but were not limited to: changes in exposure due to different rates of licensure (Frith 1992; Langley 1996; McKnight 1983; O'Connor 2000; Shope 2001; Ulmer 2000) or economic factors (Frith 1992; Langley 1996; McKnight 1983); other legislative changes (Bouchard 2000; O'Connor 2000); reductions in the target population (Langley 1996; McKnight 1983;) 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).

Six studies examined three or more years pre and post-implementation of the program (Agent 2001; Frith 1992; Langley 1996; Mayhew 2000; McKnight 1983; O'Connor 2000) while seven studies examined less than three years either pre or post-implementation of the program (Boase 1998; Bouchard 2000; Foss 2001; Ohio 2001; Shope 2001; Smith 2001; Ulmer 2000). See Table 3 for details.

Table 3. 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	-	-	-
Agent	Kentucky	16-19	licensed drivers	1,850	-6	-11	-5	-4	3
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

Table 3. Overall Crashes: all teenage drivers (*Continued*)

* per 10,000 persons									

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

Six studies presented comparable data for all crash types (Table 3; Table 4); these included driver-involved fatal, injury, and property-damage only (PDO) crashes. For 16 year-olds, the reductions in per population crash rates for the first year post-GDL ranged from 26 to 41% (four studies). Crash rates per licensed driver (three studies) were similar (19 and 31%) with the exception of the rate observed by Boase 1998 (79%). In general, adjusted rates were more conservative than the unadjusted rates. Three studies presented crash reductions for all teenagers: one per population (20%; 7% adjusted) and two per licensed driver (6 and 25%; 11 and 19% adjusted).

Table 4. 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

Table 4. Injury Crashes: 16 year old drivers (*Continued*)

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
Smith 2001	California	population	118	-4	-	-19	-	2
Ulmer 2000	Florida	population	323	-10	-11	-	-	-
Agent	Kentucky	licensed drivers	621	-35	-	-39	-	3
Smith 2001	California	licensed drivers	475	+3	-	-0.6	-	2
* per 10,000 persons								

Four studies analyzed data beyond the first year post-GDL. Unadjusted and adjusted results were similar to the initial year post-implementation. Rates did not consistently increase or decrease over time. 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)

Ten studies reported injury crash data that could be summarized as percent changes (Table 5; Table 6). Per population reductions for 16 year-olds ranged from 4 to 43% (seven studies). Adjusted rate reductions for four of six studies were more conservative; considering all six studies, differences in unadjusted and adjusted percent changes ranged from a further decrease of 1% to an increase of 10%. Two studies reported rates by licensed drivers: one showed a reduction of 35%, while the other showed an increase of 3%. No adjusted results were available for the per licensed driver rates. For all teenagers, the reductions in per population rates ranged from 8 to 25% (three studies). Adjusted rates were similar. Two studies reported rates per licensed driver; these results were similar to the per population rates. In addition, Bouchard 2000 compared the number of victims killed or injured in crashes involving learner and probationary drivers (as opposed to the number of crashes). They found a 14% decrease in rates per licensed driver, averaged over two years post-GDL. Adjusting for an internal control group increased the reduction to 17%.

Table 5. 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	-	-	-
Agent	Kentucky	16-19	licensed drivers	581	-11	-	-13	-	3
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 6. 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

Table 6. Hospitalizations: 16 year olds (*Continued*)

Langley 1996	New Zealand	licensed drivers	100	-27	-	-15	-	5
* per 10,000 persons								

All further years examined post-GDL showed rate reductions. However, they were not consistently larger or smaller than those observed for the first year post-GDL. No associations between post-GDL rates and baseline rates or quality items were evident.

Hospitalizations

Three studies reported on hospitalizations (Table 7; Table 8) although the data sources, and hence the definitions, differed. Langley 1996 studied discharges from public hospitals in New Zealand; these included drivers and passengers. Among 16 year-olds, initial reductions were 41% per population (35% adjusted) and 27% per licensed driver. The subsequent years post-GDL (two to five years) showed similar reductions. The reductions were smaller for all teenage drivers (per population 26%, adjusted 20%; per licensed driver 18%). Frith 1992 also studied hospitalizations in New Zealand. However, their study population was exclusively drivers admitted to hospital as a result of a road crash. Population-based rates were presented for all teenage drivers combined. The reduction was 32% (28% adjusted) one year post-GDL. Reductions were similar during the second year post-implementation. O'Connor 2000 examined police-reported hospitalizations of drivers in South Australia. Population-based rates were presented for all teenage drivers combined. The reduction was 23% (19% adjusted) one year post-implementation. The adjusted rates remained similar two and three years post-GDL. Unadjusted rates were not consistent (35% at year 2 and 50% at year 3).

Table 7. 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

Table 7. Hospitalizations: all teenagers (*Continued*)

Langley 1996	New Zealand	15-19	licensed drivers	84	-18	-	-25	-	5
* per 10,000 persons									

Table 8. 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
McKnight 1983	Maryland	population	2.2	+56	+56	-8	-1	3
Agent	Kentucky	licensed drivers	12.4	-43	-	-53	-	3
Boase 1998	Ontario	licensed drivers	6.6	-73	-59	-76	-55	2
* per 10,000 persons								

Fatal crashes

Eight studies presented data for fatal crashes (Table 8; Table 9). The changes in per population fatal crash rates for the first year post-GDL ranged from an increase of 56% to a decrease of 60% among 16 year-olds (three studies). Rates per licensed driver (two studies) showed a wide range as well (43 and 73%). Adjusted rates for both denominators lessened the reduction by 0 to 14%. Among teenage drivers, two studies measured per licensed driver reductions in fatalities to anyone involved in the collision. Reductions varied from 7 to 33% (adjusted 19%). O'Connor 2000 studied only driver fatalities and found a 23% reduction (adjusted 15%). Two studies compared the number of fatalities from crashes involving young drivers (as opposed to the number of fatal crashes). Frith 1992 found a per population reduction of 15% in fatalities for 15-19 year-olds. Bouchard 2000 found a decrease of 26% per licensed driver in the number of fatalities for learner and probationary drivers averaged over two years post-implementation. When they adjusted for an internal control group, the decrease was 6%.

Table 9. 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	-	-	-	-
O'Connor 2000	South Australia	16-19; number of driver fatalities	population	1.3	-23	-15	-64	-47	3
Agent	Kentucky	16-19	licensed drivers	9.2	-7	-	-19	-	3
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	-	-	-

Table 9. Fatal Crashes: all teenage drivers (*Continued*)

* per 10,000 persons									
** averaged over 3.5 year period									
*** averaged over 2 year period									
**** post-implementation rate averaged over 2 years									

Rates for subsequent years generally showed further decreases. It should be noted that these percent changes are unstable, because the baseline rates are very low; small differences in baseline and endpoint rates can create large changes. For instance, the fatal crash rate among 16 year-olds observed by McKnight 1983 increased by 1.2 per 10,000 in the first year post-GDL; this produced a percent change increase of 56. This accounts for an additional 10 fatal crashes one year post-intervention.

Night

Three programs with night driving restrictions (Table 10; Table 11) that began before midnight presented data on night-time crashes. Foss 2001 found a per population reduction of 47% for 16 year-old drivers in the first year 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 post-GDL. They found a 32% decrease in crash rates during curfew hours (22:00-05:00) for drivers with restricted licenses (Table 11). Ulmer 2000 calculated the number of actual crashes for 15-17 year-olds in 1997 (one year post-GDL) and showed that night-time (23:00-06:00) fatal/injury crashes decreased by 17%. The result from this last study is not included in the tables because they did not control for population size or for the number of licensed drivers.

Table 10. 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
Smith 2001***	California	population	4	-25	-	-50	-	2
Agent****	Kentucky	licensed drivers	80	-33	-	-42	-	3
Smith 2001***	California	licensed drivers	15	-20	-	-33	-	2
* 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 11. 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**	Kentucky	16-19	licensed drivers	109	-3	-	-14	-	3

Table 11. Nighttime crashes: all teenage drivers (*Continued*)

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									

Data were available on night-time crashes for three programs with night curfew restrictions that began at midnight or later. For 16 year-old drivers, Shope 2001 and Smith 2001 found per population percent reductions of 46% (37% adjusted) and 25% respectively in the first year post-GDL, and 57% (51% adjusted) and 50% in the second year post-GDL. The per licensed driver rates observed by Smith 2001 were more conservative (first year 20%, second year 33%). McKnight 1983 conducted a time series analysis (not included in tables) to evaluate changes in night-time crashes from 1975 to 1982 (program implemented in 1979). The authors calculated a night accident ratio which was the ratio of night-time/daytime collisions for 16 year-olds divided by the ratio of night-time/daytime collisions for the internal control group (18-21 year-olds). The night/day ratio accounts for changes in reporting and exposure that affected night-time and daytime collisions to the same extent. The authors found no decline in the ratio that would have coincided with the implementation of the licensing program. The authors compared the trend in collisions against national data and found a similar pattern, indicating that the pattern was most likely due to factors extraneous to the licensing program.

Two additional studies presented data on night-time crashes. However, the night curfew for these programs was during the permit stage (initial stage of licensure). For 16 year-old drivers, Agent 2001 found a reduction in rates per licensed driver of 33% in the first year. For teenage drivers, the effect was muted with reductions of 3%. Reductions were similar for the second and third years post-GDL. The night curfew for this jurisdiction was from midnight to 06:00. Boase 1998 found a 48% reduction in per licensed driver night-time crashes for 16-19 year-old novice drivers; the night curfew was from midnight to 05:00.

Alcohol

Data were presented on alcohol-related crashes (Table 12; Table 13) 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.

Table 12. 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***	Kentucky	licensed drivers	33	-39	-	-42	-	3
* per 10,000 persons								
** zero BAC								
*** 0.02 mg/dl								

Table 13. 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**	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	-	-	-

Table 13. Alcohol crashes: all teenage drivers (*Continued*)

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 years									

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 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

Only one study evaluated the effectiveness of a restriction on teen passengers. 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

McKnight 1983 conducted a time series analysis of convictions from 1975-1982 (program 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 the program. The pattern of changes in convictions for 17 year-olds paralleled that seen for 16 year-olds but did not reach statistical significance.

Boase 1998 presented data on convictions post-GDL by license level, but did not make any comparisons with pre-GDL measures.

Property damage

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.

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. Three studies provided results for both population and licensed driver denominators, thus allowing for direct comparisons (Foss 2001; 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 3], 16 year-old injury crashes [Table 5], 16 year-old and all teenage hospitalizations [Table 7; Table 8], 16 year-old night crashes [Table 10], and passengers injury rates with 16 year-old drivers). All studies that examined both 16 year-olds separately and groups of teenagers consistently found reduced reductions for the teenage group as compared to the 16 year-olds (Ulmer 2000; Frith 1992; Mayhew 2000; Langley 1996; Boase 1998; Agent 2001).

Time series analyses

Langley 1996 analyzed hospital discharge counts using an auto-regressive integrated moving average (ARIMA) model. They found a 23% reduction in the 15-19 year-old group and a net reduction of 7% when considering a 16% decline in the 25+ internal control group. Two potential surrogate markers for confounding (striking and assault injuries) gave opposing results and supported the authors conclusions that "there was no other common factor affecting all types of injury events involving 15-19 year-olds, which could have also lead to a reduction in the incidence of motor vehicle crashes".

McKnight 1983 conducted a number of ARIMA time series analyses. The ratio of the 16 year-old group daytime collision count to the 18-21 year-old group collision count showed an approximate 5% reduction. This result was just shy of statistical significance (p=0.08). The external control group (Virginia) did not show a similar reduction.

Mayhew 2000 also conducted ARIMA time series analyses. For all crash types, the analysis showed a decrease of approximately seven crashes per month (P<0.05) for 16 year-olds. There were no significant reductions for the internal (25+) or the external control groups. None of the ARIMA time series analyses for these three studies reported adjusting for population size or for the number of licenses.

O'Connor 2000 conducted a series of regression "cut-point" analyses to evaluate whether the slope of per population hospitalization rates (by year) significantly changed at any year within the time span of the analysis. These rates were adjusted for the results of an internal control group (20+ age group). A graph of the excess serious injury rate over time was plotted (i.e. 16-19 year-old rates of police-reported hospitalizations minus rates among the 20+ age group). The authors reported that the residual mean square was minimized for 1988 and 1989 (the program was implemented in November 1989) suggesting that GDL was having a positive impact. Further details such as significance and magnitude of the decrease (plots showed a decrease) were not reported.

DISCUSSION

Overall, the evidence indicates that GDL is effective in reducing crash rates of teenage drivers, although the magnitude of the reduction is unclear. Reductions were seen for all types of crashes among 16 year-olds and all teenage drivers, although the impact varied across jurisdictions. While a causal association between GDL and crash reductions cannot be proven through observational study designs, the effectiveness of GDL is supported by reductions in rates of all crash types, (almost entirely) consistent positive results across studies and within studies when adjusting for internal controls, clear temporal relationship between the implementation of GDL programs and observed reductions, and the plausibility that reducing driver exposure to high-risk situations would reduce crash rates.

While the principles underlying GDL are widely accepted, there is variability in the design and strength of different programs; in fact, "some graduated licensing programs are "in name only"" (Williams 2003a). Hence, some of the programs that have been included in this review may not be considered by some as true GDL. For instance, the program in Ontario has no real restrictions during the intermediate stage of licensure. The program in Kentucky (as it existed when it was evaluated in the included study) was considered to be a partial GDL program (Agent 2001). The program in South Australia has been criticized because the major restrictions relate to the age of licensure rather than the components that are considered key to GDL. Our intent was to be overly inclusive in order to evaluate the spectrum of different programs that are considered by some to be GDL. This choice was motivated by our desire to provide relevant information for policy-makers who may want to implement programs in their own jurisdictions. Because of the political realities and different social environments, the programs accepted for implementation will vary from the ideal

GDL system. Additionally, we informally 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 possibly because of the limited number of studies and/or the wide variation in programs. Despite the structure of the programs, the research shows that all appear to be having positive effects.

Due to issues related to logistics and feasibility, research in this area involves studies with an ecological design. Ecological studies are recognized as methodologically weaker. However, they are often the most appropriate with which to answer questions regarding the impact of legislative changes. 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 three studies for which we had both population and licensed driver denominators. 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).

One of the more important limitations of the component studies was the relatively short period of time evaluated post-intervention: seven of the thirteen studies evaluated less than three years post-GDL. 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. Several studies conducted time series analyses and the results were generally conservative compared to the range of findings reported overall.

One of the limitations of this review is that specific recommendations cannot be made regarding program design. While we can conclude that certain components (e.g. night-time curfews) showed a positive effect, we cannot directly compare programs with and without these specific components because of other confounders. It is of interest that 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 eight of the twelve programs had a night curfew during the intermediate phase and only three of the curfews began before midnight. There is also evidence supporting restrictions on the number of passengers (Aldridge 1999; Chen 2000; Doherty 1998; Preusser 1998). However, only two 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.

While it is desirable in a systematic review to provide an overall summary measure of the estimate of effect, it was not appropriate to do so in this situation. 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). 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 unclear.
- The relative contribution of different provisions within a GDL program remains uncertain.

Implications for research

- 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 year olds (data presented for 16-16.5, 16.5-17) secondary: 17 control: 19, >19 (some data presented for 18 year olds) Program applies to drivers < 18.
Interventions	Oct 1996 Level 1: min age 16; min holding period 6 mos; supervision (licensed driver 21+); no driving midnight-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; nighttime crashes (midnight-6 am); 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

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 year olds 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 midnight-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.

Boase 1998 (*Continued*)

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 (ie level 2 drivers only); alcohol-related crashes (BAC of driver above legal limit); night-time crashes (midnight-5am) ; 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 years old
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
Notes	Quebec

Foss 2001

Methods	ecological design: single group studied over time years studied: 1999 versus 1996 and 1997
Participants	16 year olds 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).

Foss 2001 (*Continued*)

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

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	15-19 (aggregated and separated by year); Control group: 25+ Program applies to 15-24 year olds.
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); presents data on casualty and cost savings, compliance with restrictions
Notes	New Zealand

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 years (struck by/against, assaults) Program applies to 15-24 year olds.
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.

Langley 1996 (*Continued*)

	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

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 midnight-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

McKnight 1983

Methods	ecological design: multiple groups studied over time years studied: 1975-82
Participants	primary: 16 year olds 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.

McKnight 1983 (*Continued*)

Outcomes	all crashes (fatal, injury, property damage only as reported by state police) by nighttime (01:00-06:00) / daytime occurrence; traffic convictions
Notes	Maryland

O'Connor 2000

Methods	ecological design: multiple groups studied over time years studied: 1983-1992
Participants	16-19 year old 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 on or after July 1, 1998 and 16 yo who received license under new GDL law) vs pre-GDL group (16 and 17 years in 1996 and 1997); secondary comparison: 15, 16, 17 yo for 1988-1999 control group: 25-54 Program applies to drivers <18.
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 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; liense can be canceled if convicted of certain traffic-related violations; license can be canceled or revoked if convicted of any alcohol-related offense, 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

Ohio 2001 (*Continued*)

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

Shope 2001

Methods	ecological design: single group studied over time years studied: 1996 versus 1998, 1999
Participants	Age group studied: 16 year olds. Control group: 25+. Program applies to drivers <18.
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 midnight-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), nighttime crashes (midnight-04:59); single and multiple vehicle crashes; alcohol-related crashes ("had been drinking" indicated on police report)
Notes	Michigan

Smith 2001

Methods	ecological design: single group studied over time years studied: 1999 and 2000 vs 1997
Participants	age group studied: 16 year olds. 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 yrs for first 6 mos unless supervised by licensed driver >25 years; no unsupervised driving 00:00-05:00 for first 12 mos; min age next stage 18.

Smith 2001 (*Continued*)

	Violation of GDL requirements punishable by 6-month suspension of driving privileges and possible fines or community service. Programme 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 year olds; nighttime crashes (00:00-05:00)
Notes	California (San Diego County)

Ulmer 2000

Methods	ecological design: multiple groups studied over time years studied: 1997 versus 1995
Participants	age groups studied: 15, 16, and 17 year olds (primary focus); 18 year olds (secondary). Control groups: 25-54 year olds, external jurisdiction (Alabama). Program applies to drivers 15-17 years old.
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]*

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.
Jones 1994	Evaluation of a provisional licensing program with only two stages.
Ulmer 2001	Evaluates first phase of graduated licensing.

DATA AND ANALYSES

This review has no analyses.

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: 22 February 2004.

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HISTORY

Protocol first published: Issue 4, 2001

Review first published: Issue 2, 2004

CONTRIBUTIONS OF AUTHORS

LH coordinated the project, drafted the protocol and final review, and contributed to literature searching, relevance and inclusion screening of articles, assessment of study quality, data extraction, and data analysis.

NW coordinated the data analysis and contributed to writing the protocol, assessment of study quality, data extraction, and writing the review.

KR contributed to searching, relevance screening, data extraction, data analysis, and writing the review.

JP provided the idea, initiated the project, and contributed to inclusion screening and editing the review.

CS contributed to protocol development, interpretation of results, and editing the review.

TPK contributed to protocol development, interpretation of results, and editing the review.

DECLARATIONS OF INTEREST

None known.

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INDEX TERMS

Medical Subject Headings (MeSH)

*Automobile Driving [legislation & jurisprudence; statistics & numerical data]; *Licensure [legislation & jurisprudence; standards]; Accidents, Traffic [*prevention & control; statistics & numerical data]; Adolescent

MeSH check words

Humans