NATIONAL STUDY OF TEEN DRIVER LICENSING SYSTEMS AND GRADUATED DRIVER LICENSING PROGRAM CORE COMPONENTS

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ABSTRACT

SCOTT MASTEN: National Study of Teen Driver Licensing Systems
and Graduated Driver Licensing Program Core Components
(Under the direction of Stephen Marshall)

Sixteen- and seventeen-year-old drivers have higher crash rates than any other age group. Graduated driver licensing (GDL) programs, which are specialized driver licensing systems for beginner drivers, have been implemented in most U.S. states to reduce young teen drivers' exposures to high-risk driving situations while they gain driving experience. Driver fatal crash involvements for all U.S. states from 1986-2007 were analyzed using Poisson regression models to estimate the associations of GDL programs with 16-, 17-, 18-, and 19-year-old crash incidences. GDL programs were reliably associated with 16–26% lower driver fatal crash incidence for 16 year olds, but 10–12% higher incidence for 18 year olds, dependent upon the number of license restrictions included during the intermediate licensing stage. GDL programs with two license restrictions during the intermediate licensing stage were marginally associated with 9% lower 17-year-old driver fatal crash incidence. The benefits of GDL programs in terms of reducing 16- and 17-year-old driver fatal crash involvements were found to outweigh the increased involvements among 18 year olds associated with such programs. Overall, 544 fewer net 16–19-year-old driver fatal crash involvements during the 12-year period since the first U.S. GDL program was implemented are attributable to having specialized teen driver licensing systems. The majority of the net crash reduction (470 involvements) is attributable to implementing three-stage GDL

programs. At least one calibration for each GDL program core component, except supervised driving hours, was associated with a net decrease in 16–19-year-old driver fatal crash involvements. The calibrations of the GDL program core components associated with the largest net 16–19-year-old driver fatal crash involvement savings are: (a) a minimum learner stage entry age of 16 years; (b) a minimum learner permit holding period of 9–12 months; (c) no minimum number of required supervised driving hours; (d) an intermediate licensing stage starting at age 16.5–17 years; (e) a nighttime driving restriction starting at 11:00 pm; (f) a passenger restriction allowing no more than one teen passenger that lasts for 6 months or longer; and (g) unrestricted licensure starting at age 17–17.4 years.

DEDICATION

To those who believed in me, especially Tammy Bourg, Linda Fidell, Rob Foss, Robert Hagge, Steve Marshall, Ray Peck, and Heather Masten. The coding of teen driver licensing systems and graduated driver licensing program core components was based largely on historical documentation of changes in teen driver licensing systems maintained by the Insurance Institute for Highway Safety and existing coding shared by the American Automobile Association Foundation for Traffic Safety. The coding of changes to other highway-related laws was based on existing coding magnanimously shared by Thomas Dee, Donald Freeman, Michael Lovenheim, and Alexander Wagenaar. The benevolence demonstrated by having these researchers share their hard work was tremendous. The coding of the various laws could not have been updated, corrected, and completed without the help of numerous legislative and licensing officials across the country who responded to my inquiries and went above and beyond to help me. To all the persons above – THANK YOU.

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ABBREVIATIONS

95% CI	95% confidence interval
AAAFTS	American Automobile Association Foundation for Traffic Safety
CLR	Confidence Limit Ratio
FARS	Fatality Analysis Reporting System
FHWA	Federal Highway Administration
GDL	Graduated driver licensing
GEE	Generalized estimation equations
HSRC	Highway Safety Research Center
IIHS	Insurance Institute for Highway Safety
RR	Rate ratio
NHTSA	National Highway Traffic Safety Administration
TIRF	Traffic Injury Research Foundation
TRAID	Traffic Accident Information Database

CHAPTER 1

I. INTRODUCTION AND REVIEW OF LITERATURE

A. Overview of Crash Rates by Driver Age

Though motor vehicle crashes are one of the top 10 causes of mortality for all age groups, they are the leading cause of death in the United States for persons 16–19 years of age (National Center for Injury Prevention and Control, 2006). Since 2000 over 23 thousand 16–19-year-old drivers and 14 thousand passengers have been killed in motor vehicle crashes, with an average of almost five thousand 16–19-year-old driver and passenger deaths per year from 2000–2008 (National Highway Traffic Safety Administration [NHTSA], 2010). In California during this time period, 1,750 drivers and 1,553 passengers were killed. When crash involvement rates are plotted by driver age, those for younger drivers (less than 25 years) tend to be higher than those for most other age groups (Williams, 2003). However, the actual shapes of these distributions vary considerably as a function of how the ages are grouped into categories (e.g., single years vs. 5-year groups), type of crashes used for the rate numerator (e.g., all crashes vs. fatal/injury crashes), and the rate denominator used to represent exposure (e.g., population, licensees, or mileage). For example, Figure 1 shows national crash involvement rates per million miles traveled by driver age (Williams, 2003).

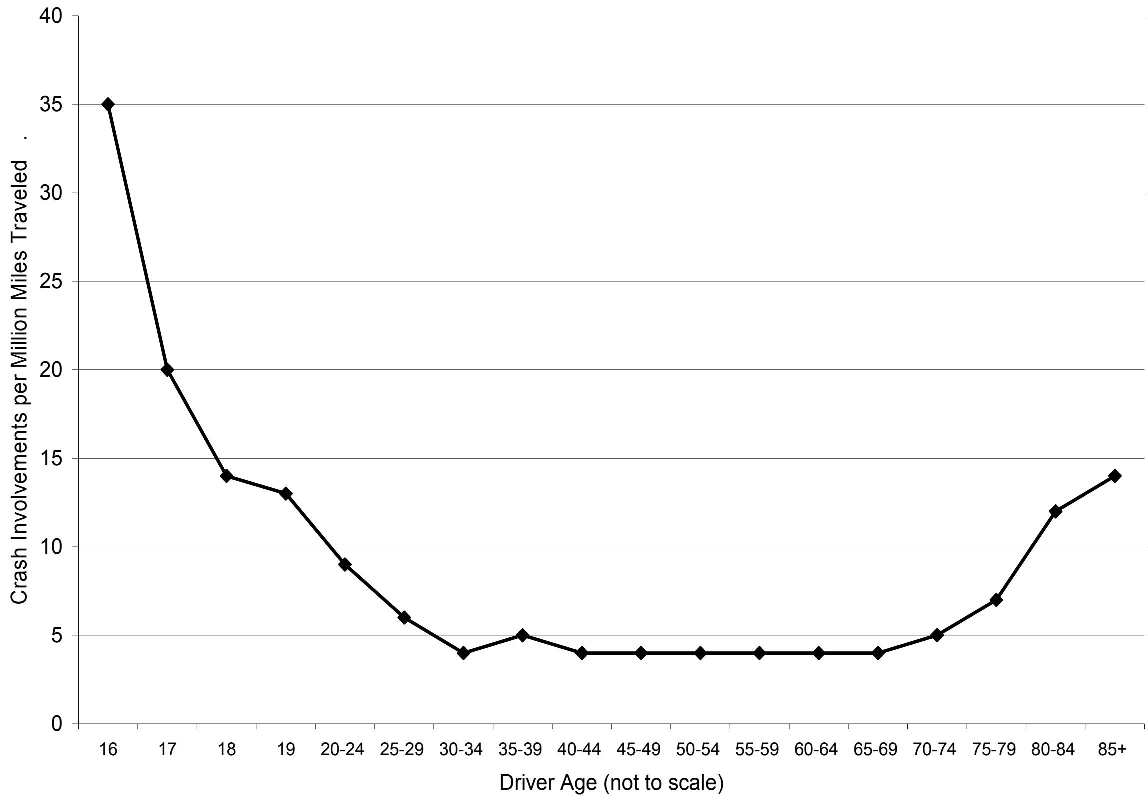


Figure 1. Crash involvement rates per million miles traveled by driver age, 1995 (data source: Williams, 2003, Table 1).

Mileage-adjusted driver crash rates are highest for 16 and 17 year olds, plateau to some degree at an elevated rate for 18 and 19 year olds, continue to decline until around age 30, and are relatively flat until around age 70 when they start to creep back up.

There is nothing inherently meaningful about “teen” drivers, though we conventionally talk about teen drivers as a single group. The teen driver age groups in Figure 1 are intentionally not aggregated to emphasize the fact that 16 and 17 year olds have different crash rates than do 18 and 19 year olds. Figures that show 16–19 year olds as a group are useful for emphasizing the relative risk of teens compared to drivers in other age groups, but unavoidably give the appearance that crash risk is homogeneous across all teen age groups. This conceals the large differences between 16 and 17 year olds and older teens. Six states still licensed persons ages 14 or 15 years to drive unsupervised as of 2007, though none allowed completely unrestricted driving until age 16. For purposes of this study, drivers younger than age 16 are excluded and “teen drivers” refers to drivers from 16 to 19 years of age. Crash rates differ among the individual ages in this grouping, the causes behind their crash rates probably differ, and hence the interventions that aim to reduce their crashes likely do not have a homogenous effect across all teen drivers. For these reasons the age groups are analyzed separately in almost all cases, and the results from these stratified analyses are combined to characterize teen drivers as a group.

The denominator choices commonly used to create crash rates by driver age are total population (per capita), number of licensed drivers, and miles traveled. Because age groups differ in population size, percentage of the population licensed to drive unsupervised, and annual mileage, the denominator choice also results in different crash rate distribution shapes across driver ages (Williams, 2003). On all three commonly used crash indices, the youngest teens (16 and 17 year olds) have total crash rates that are higher than any other group of drivers aged 25 years or older (Janke, Masten, McKenzie, Gebers, & Kelsey, 2003; Williams, 2003). As such, 16–17-year-olds’ crashes are a major source of morbidity and mortality worthy of intervention (Martinez, 2005). The crash statistics for California approximately follow the same patterns as these national statistics (Janke et al., 2003).

This manuscript presents a study of a crash intervention called Graduated Driver Licensing (GDL), which is a family of specialized driver licensing systems for beginner drivers. GDL programs aim to provide 16–17-year-old drivers with more on-road experience under conditions of reduced risk, because teens with more on-road experience tend to have lower crash rates (Cooper, Pinili, & Chen, 1995; Ferguson, 1996; Gregersen, Berg, Engstrom, Nolen, Nyberg, & Rimmo, 2000; Mayhew & Simpson, 1990; Simpson & Mayhew, 1992; Waller, 1975). Although 16 and 17 year olds are the main focus of most GDL programs, these programs might also be associated with effects on older teens. For example, there is some evidence that GDL programs may be associated with higher crash rates among some older teens (e.g., Males, 2007; Vanlaar, Mayhew, Marcoux, Wets, Brijs, & Shope, 2009), possibly due to younger teens delaying licensure until they are no longer subject to the GDL requirements (McKnight, Peck, & Foss, 2002; Williams & Mayhew, 2008). Hence this study also included 18 and 19 year olds so that any changes in their crash rates associated with GDL programs could be estimated, along with the overall net association for all "teen drivers" associated with GDL programs. The next section summarizes some reasons why 16 and 17 year olds crash at higher rates than do drivers in other age groups and explains why GDL programs are a viable intervention for reducing crashes among 16 and 17 year olds. Since GDL programs became common, the meaning of "licensed" is no longer a simple dichotomous notion for teens as these systems have three different licensing stages (i.e., learner, intermediate, and unrestricted). The first stage allows driving only when supervised by an adult licensed driver, which was more commonly referred to as a learner or instruction permit in the past rather than as a "learner license." For clarity throughout this manuscript the term "licensed" refers to being licensed to drive unsupervised by an adult—whether initially subject to special driving restrictions (intermediate license) or not (unrestricted license)—and the term “learner permit” refers to being licensed to drive only under the supervision of a licensed adult.

B. Reasons Why 16 and 17 Year Olds Have High Crash Rates

1. Inexperience at Driving

It should not be surprising that 16–17-year-old drivers have high crash rates. Driving is a cognitively complex task that requires more than trivial skill to master (McKnight, 1996; Waller, 2003). Most 16 year olds and many 17 year olds are just learning basic driving skills and have not yet accumulated much driving experience. The scientific evidence regarding the power law of learning predicts that the number of errors made by learners of a procedural skill – such as driving – would decrease rapidly over initial exposures followed by smaller improvements with further practice (Anderson & Fincham, 1994). Consistent with the learning curve predicted by this law, the most dangerous period of driving for 16 and 17 year olds is immediately after they have been licensed to drive unsupervised, particularly in the first several months (Harrington, 1972; Mayhew, Simpson, & Pak, 2003; McCartt, Shabanova, & Leaf, 2003). This can be seen in Figure 2, which shows the percentage of California 16–17-year-old drivers who had their first police-reported crash each month after licensure to drive unsupervised.

The literature on driving experience and crash rates for young teens indicates that crash involvement of newly licensed 16–17-year-old drivers as a group decreases remarkably within the first months of unsupervised licensure, after which the decline continues for years at a less steep rate (Masten & Foss, 2010; Mayhew et al., 2003). If "time licensed" can be taken to be a crude surrogate for driving experience, this suggests that more driving experience is associated with reduced 16–17-year-old crash rates. Supervised driving while on a learner permit is a relatively safe type of driving exposure (Mayhew et al., 2003; Williams, 2003; Williams, Preusser, Ferguson, & Ulmer, 1997) that allows novice 16 and 17 year olds to gain driving experience while driving under conditions of reduced risk (Evans, 1987; Mayhew, 2003; Waller, 2003; Warren & Simpson, 1976; Williams, 1994).

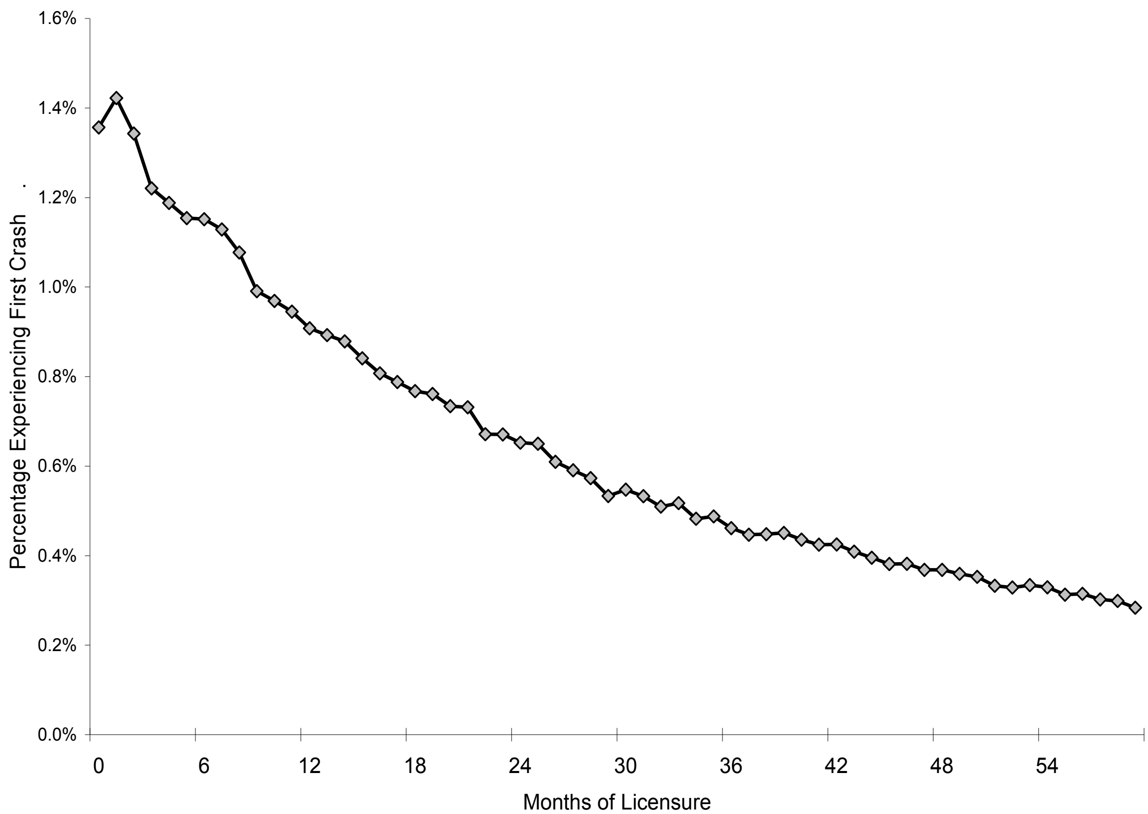


Figure 2. Percentage of California 16–17-year-old drivers crashing for the first time each month after they are licensed to drive unsupervised.

2. Age-Related Surrogate Factors

While new learners, regardless of age, are over-involved in crashes, 16–19-year-old novices have the highest initial crash involvement rate of any age group, which suggests there are other age-related reasons for their high crash rates beyond mere inexperience (Cooper et al., 1995; Levy, 1990; Mayhew et al., 2003; McCartt, Mayhew, Braitman, Ferguson, & Simpson, 2009). For example, Figure 3 shows crash rates for novice drivers ages 16–19 compared to those 20 or older (Mayhew et al., 2003).

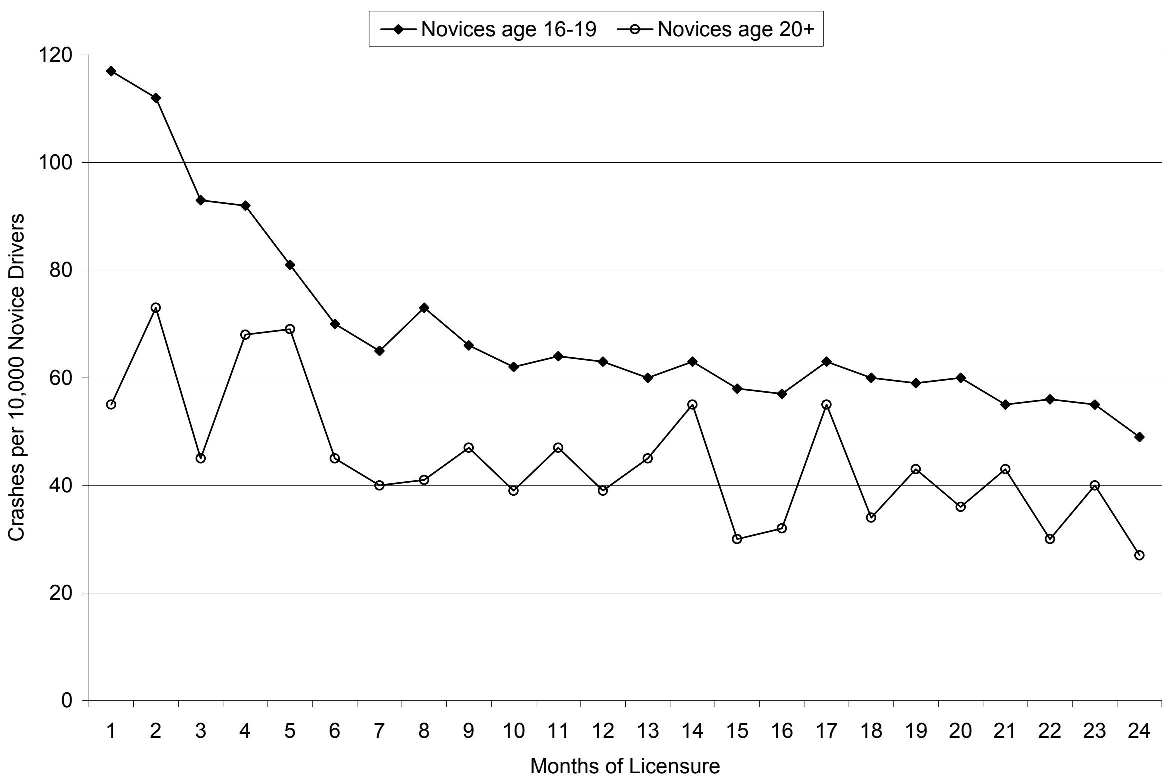


Figure 3. Crash rates per 10,000 novice drivers during each month after initial licensure by age group (data source: Mayhew et al., 2003, Figure 2).

The crash rates in the figure for novice 16–19 year old drivers are higher than those for novice drivers ages 20 or older during each month after initial licensure for at least

2 years. That is, given the same level of inexperience and driving exposure, younger novices tend to have higher crash rates than do older novices, and even a 1-year increase in age at licensure is associated with lower crash rates among young teen drivers (Cooper et al. 1995; LaBerge-Nadeau, Maag, & Bourbeau, 1992; Levy, 1990; Maycock, Lockwood, & Lester, 1991; Mayhew et al., 2003; Waller, Elliott, Shope, Raghunathan, & Little, 2001). The vague term "age-related" is used here because age *per se* does not cause higher crash risk. Age is simply a surrogate measure for other constructs for which there is sometimes little agreement or supporting evidence in the literature regarding 16 and 17 year olds. The age-related variability in young teen crash rates has been attributed to, or called, many different things in the literature such as: risk-taking; risky behavior; hazard perception/recognition; over-confidence; youth; adolescence, developmental issues, and immaturity; just to name a few.

There is surprisingly little empirical evidence specific to 16–17-year-old drivers to help to explain their "age-related" higher crash risk. The numerous studies that are commonly cited in this regard (e.g., Deery, 1999; Finn & Bragg, 1986; Jonah 1986; Matthews & Moran, 1986) use overly broad definitions of "young drivers," including all persons under the age of 25 years-old. There are clear differences in crash rates for teens compared to young adults. In fact, there are large differences in crash rates between younger and older teens, as was clearly illustrated in Figure 1. Of the studies on age-related crash factors that have specifically disaggregated 16–17-year-old drivers from other age groups, few have controlled for the strong influence of experience (McCartt et al., 2009). In fact, some simply use age as a surrogate for driving experience, which further confuses the issue.

Beyond the topic of crashes, there are dramatic, relevant differences in cognitive functioning and skill acquisition between 16–17 year olds and older teens, and between teens and persons in their early 20s. Adolescence is an important period for coordinating a wide range of cognitive and brain systems into a self-aware, guided, and monitoring system of conscious control (Keating, 2004; Steinberg, 2007). There is a steep learning curve for the acquisition of skill expertise, especially when such acquisition requires deliberate, consciously-guided effort (Ericsson, 2002; Keating, 2004). While there is little doubt that 16 and 17 year olds have the physical ability to be able to drive safely, what they may lack are well-developed cognitive functions such as processing efficiency and working memory, which allow the automation of complex tasks (like driving) and enable much more complex performance (Keating, 2004; McKnight, 1996). Because cognitive functions have growth patterns that are robust earlier in age but become asymptotic as the older ages of adolescence are reached, these functions are probably less well developed in 16 and 17 year olds than they are in older teens and adults (Keating, 2004).

Therefore, it is not certain whether the findings from studies based on broader age groups (e.g., all teens 16–19 or young drivers 16–24) apply to 16 and 17 year olds, although it is routinely assumed to be so in the traffic safety literature. For example, in a widely-cited compendium of proceedings from the First Annual International Symposium of the Youth Enhancement Service called *New to the Road: Reducing the Risks of Young Motorists* (Simpson, 1996), the age-related factors for adolescent drivers identified were: (a) lower self-perceived risk of crashing; (b) lower self-perceived benefits from preventative actions; (c) driver overconfidence; (d) peer pressure; and (e) perceived rewards of risky driving

(Irwin, 1996). Of the eight research articles used to justify these conclusions, not one presented results separately for 16 and 17 year olds. Teens were combined into a single group and in three instances persons 20 years of age or older were considered "adolescents."

Another example of generalizing findings for a broader age group to 16 and 17 year olds is the frequent assertion based on findings that alcohol is a primary cause of serious crashes for adults of legal drinking age, that alcohol use is also a major reason for the high crash rates of teenage drivers (e.g., Ballesteros & Dischinger, 2002; McCartt et al., 2003; McGwin & Brown, 1999; Neyens & Boyle, 2007). In reality, alcohol is less commonly involved in fatal crashes for 16 and 17 year olds than for any other age group younger than 55 (NHTSA, 2005). The attribution of alcohol use as a major reason for 16–17-year-old crashes comes from surveys that lump all drivers from 16–20 years of age into a single category (Voas, Wells, Lestina, Williams, & Green, 1998; Zador, Krawchuck, & Voas, 2000) and a 2-decades-old literature review showing that the relative risk of a fatal crash increases as a function of blood alcohol content more so for 16–19 year olds combined than for other age groups (Mayhew, Donelson, Beirness, & Simpson, 1986).

Several studies have characterized the person-, vehicle-, environmental-, and driving-related factors associated with 16–17-year-old crashes, with the goal of identifying characteristics prevalent in these crashes (e.g., Ballesteros & Dischinger, 2002; Braitman, Kirley, McCartt, & Chaudhary, 2008; Gonzales, Dickinson, DiGuiseppi, & Lowenstein, 2005; Lam, 2003; Massie, Campbell, & Williams, 1995; McKnight & McKnight, 2003; Ulmer, Williams, & Preusser, 1997). From these studies there is evidence that 16–17-year-old crashes are more likely than crashes for older teens or adult drivers to involve single-vehicles, driving too fast, lack of attentiveness, leaving the roadway, and curved roads. Furthermore, their crashes occur less often during inclement weather and are less likely to involve alcohol. The 16–17-year-old drivers are also more likely to be found at-fault for the crash and be cited for a moving violation by the reporting officer. As described in the next section, two of the most replicated findings across characterizations of 16–17-year-old driver crash risk factors are the presence of teen passengers and nighttime driving. While the various characteristics of 16–17-year-old crashes have been described, the larger goal of determining the specific age-related factors that cause these crashes is difficult. Many of the factors likely relate to inexperience rather than driver age (McKnight & McKnight, 2003).

While it is clear that younger age at licensure is associated with higher crash rates, the etiology of this effect is not understood. The types of driver errors made by 16 and 17 year olds in crashes do not seem to reflect deliberate risk-taking or over-confidence as is commonly mentioned in the literature (e.g., Irwin, 1996). Instead they seem to reflect skill deficiencies expected from the initial learning curve associated with learning to drive (McKnight & McKnight, 2003). This issue is probably complicated by youthfulness, but everything that involves more than trivial skill, especially savvy or "cognitive skill," takes time and practice to learn (Anderson & Fincham, 1994; Keating, 2004). Hence, the high crash rates for 16 and 17 year olds are probably mostly due to the large number of errors they make during the initial stages of learning the cognitively complex skills involved in driving (Anderson & Fincham, 1994; McKnight, 1996; McKnight & McKnight, 2003; Waller, 2003).

The existing literature does not appear to provide clear evidence that identifies the specific age-related factors causing the higher crash involvement rates for 16 and 17 year olds. It seems to be the case, however, that interventions that directly or indirectly raise the age at which young teens drive unsupervised, particularly if they do not reduce the amount of time allowed for supervised driving, can decrease the crash rate for this age group. The most obvious intervention would be simply to raise the minimum unrestricted licensing age without changing the age at which a learner permit could be obtained. The related strategy of keeping the licensing age the same, but lowering the age at which supervised instruction can begin may also reduce 16–17-year-old crash rates (Gregersen et al., 2000).

3. High-Risk Driving Circumstances (Nighttime Driving and Teen Passengers)

Numerous studies have documented that the crash rates of 16–17-year-old drivers are higher when they transport other teen passengers and when they drive during the nighttime hours (Chen, Baker, Braver, & Li, 2000; Preusser, Ferguson, & Williams, 1998; Rice, Peek-Asa, & Kraus, 2003; Williams, 1985, 2003). Nighttime crash rates are higher for all ages, but the day-night differential is much greater for 16–17-year-old drivers (Williams, 2003). Whereas only 15% of 16–17-year-old driving occurs at night (9:00 pm–6:00 am), almost 40% of their fatal crashes occur during this time (Lin & Fearn, 2003; Williams & Preusser, 1997). That is, although they do not drive much at night, their per-mile fatal crash rate is still high.

Chen et al. (2000) found that the fatality risk of 16–17-years-old drivers is 40% to 207% higher, depending upon the number of passengers, when they are transporting teen passengers than when they are not, and that the relative risk of a driver fatality is higher as the number of teen passengers increases. When 16–17-year-old drivers transport three or more teen passengers, their crash risk is about four times greater than without passengers (Williams, 2003). Direct observation of high-school age drivers with and without teen passengers provides some evidence that may help explain why 16 and 17 year olds' crash rates are higher when they transport other teens. Specifically, young teen drivers transporting teen passengers have been found to drive faster and have shorter following distances, particularly if the passenger is male (Simons-Morton, Lerner, & Singer, 2005).

Teen passengers and nighttime driving may have even more detrimental synergistic effects. For example, the highest overall crash risk for 16–17-year-old drivers is when they transport teen passengers at night (Chen et al., 2000). However, some of the higher nighttime crash risk of 16 and 17 year olds may be spurious. According to sociological theory, "nighttime" is a social construct that is more than just darkness; it is characterized by the types of people and activities that occur during the nighttime (Melbin, 1978). Hence, 16 and 17 year olds who drive at night, especially late at night, probably differ in important ways from those of the same age who drive only during daylight. Recent empirical evidence suggests that darkness *per se* is associated with only a moderate increase in crash risk; hence the high crash risk associated with nighttime driving is likely due to other factors rather than low light conditions alone (Johansson, Wanvik, & Elvik, 2009). Alternatively, 16 and 17 year olds who may be safe drivers during the daytime may just drive differently during the nighttime hours due to reduced visibility during darkness, inexperience at driving when tired, or for other reasons associated with nighttime.

The reasons why 16–17-year-old crash risk is so much higher at night and when transporting teen passengers are not well understood. Although nighttime driving is associated with greater fatal crash involvement risk for drivers of all ages (though not to the same extent as for 16–17 year olds), the higher crash risk associated with transporting passengers is more unique to teen drivers (Williams, 2003). While there is a lack of understanding about why carrying passengers is more risky for teens, it is fairly certain that interventions that reduce the exposure of 16 and 17 year olds to these high-risk situations have a good chance of reducing their crash rates.

C. Description and Rationale of Graduated Driver Licensing (GDL) Programs

Driving is a cognitively complex task that requires the acquisition of advanced skills from repeated exposures over an extended time period to be performed well (McKnight, 1996; Waller, 2003). Historically, the licensing systems in the U.S. generally have not adequately addressed the need for young novices to gain experience under conditions of low task-demand before exposing them to the full range of risks associated with unrestricted driving. Rather, the tendency was for young novices to be given classroom instruction, a few hours of behind-the-wheel training, and then be exposed unencumbered to the full range of risky driving conditions, but with expedited penalties for making errors (Waller, 2003). The conceptual underpinnings of GDL programs were developed in the 1970s as a way for young drivers to be gradually introduced to driving by applying restrictions during their initial skill acquisition (Waller, 1975, 2003).

GDL programs are strongly predicated upon the nature of human learning. Specifically, that it takes a long time to learn complex tasks, that learners make more errors early in the learning process, that it takes longer to accomplish tasks early in the learning process, and that improvement occurs (i.e., errors decrease) in a manner approximating a power function (Anderson & Fincham, 1994). GDL programs are designed to provide the practical experience needed to move novice learner drivers along their learning curves, while keeping conditions as safe as possible. Hence, the main idea behind GDL programs is to allow novice drivers to gain on-road experience under conditions that minimize their overall crash risk (Foss & Goodwin, 2003; Mayhew, Simpson, & Singhal, 2005). This approach is supported by research showing that teen drivers with more real-world driving experience tend to have lower crash risk (Cooper et al., 1995; Ferguson, 1996; Gregersen et al., 2000; Mayhew & Simpson, 1990; Simpson & Mayhew, 1992; Waller, 1975).

GDL programs also address the driving circumstances under which teens are known to have higher crash risk (nighttime driving and transporting teen passengers) and often increase the age at which teens are allowed to drive unrestricted. Rather than expose new drivers to the complete range of driving conditions from the start of licensure, GDL programs restrict new drivers to safer conditions until they gain more driving experience and skill. The initial licensing restrictions are removed in a gradual and systematic manner to expose novice drivers to successively more risky driving conditions until they are driving unrestricted, but with more on-road experience (Mayhew et al., 2005; Williams & Mayhew, 2004). Because they aim to reduce the exposure of new drivers to higher-risk driving until they gain more experience, improve their skill, and are somewhat older, GDL programs address all three major reasons discussed earlier for high 16–17-year-old crash rates (i.e., inexperience, age-related surrogate factors, and high-risk driving circumstances; Ferguson, 2003). However, the most salient effect associated with GDL is likely exposure reduction from the longer learner permit periods, which raise the licensing age and reduce the numbers of young teens seeking licensure (Karaca-Mandic & Ridgeway, 2010; Margolis, Masten, & Foss, 2007; McCartt, 2001; McKnight & Peck, 2003; McKnight et al., 2002; Preusser & Tison, 2007). That is, there is little evidence that GDL actually makes teens safer drivers *per se*, though findings from one recent cohort study suggest that 16 year olds licensed to drive under a GDL program with a long (12 month) learner permit holding period experience lower crash incidence during the first 5 years of unsupervised driving than those licensed before GDL (Masten & Foss, 2010).

True GDL programs include three different stages of licensure: (a) a mandatory minimum learner permit period during which new drivers are only allowed to drive under the supervision of a licensed adult; (b) an intermediate period during which the new drivers are allowed to drive unsupervised, but are subject to licensing restrictions regarding passenger ages and the times during which they may drive; and (c) a final stage of unrestricted licensure allowing driving under all conditions. As novice drivers systematically move through these stages, the restrictions that limit their exposure to risky driving conditions are gradually removed; hence the name "graduated" driver licensing (Simpson, 2003). With two exceptions, GDL programs in the U.S. apply only to novice drivers younger than age 18.

The seven core components of teen driver licensing systems in general, and GDL programs specifically, are: (a) learner stage minimum entry age, (b) required learner permit minimum holding time period, (c) number of required supervised driving hours, (d) minimum intermediate licensing age, (e) intermediate licensing stage nighttime driving restriction, (f) intermediate licensing stage passenger driving restriction, and (g) minimum unrestricted licensing age. Various combinations of these licensing components and quantitative/qualitative differences in how they are applied (i.e., calibrated) form the teen driver licensing systems in every U.S. state. Though Maryland and California adopted some elements of GDL in the 1980s (they were called provisional driver licensing programs at the time), the first genuine GDL program was enacted in New Zealand in 1987 (Mayhew et al., 2005). During the 1990s U.S. states began to implement true multi-stage GDL programs as well.

GDL programs in the U.S. hardly represent a single homogeneous intervention that can be called “GDL.” Rather there are many different GDL programs that vary in age and time criteria, lengths of the learner permit and restricted license stages, required hours of supervised practice, and types and lengths of license restrictions included (Insurance Institute for Highway Safety [IIHS], 2009a). While all states have had a minimum licensing age for decades, the use of the other program components for licensing teens has varied greatly both between states and within each state over time. For example, some states had a minimum learner permit holding period or a teen nighttime driving restriction for decades (though at least one of the nighttime restrictions was a general curfew rather than driving-specific restriction), while others have only recently implemented any of the components that define specialized teen driver licensing systems (Federal Highway Administration [FHWA], 1986). Even today there are states that have adopted only a few of the program components, while others have implemented them all (IIHS, 2009a). Over the past 20 years a teen driver licensing system in a particular state may have been a one-stage system (i.e., teens are given completely unrestricted licenses upon completing their application), some form of two-stage system (i.e., with a minimum learner permit holding period or some type of unsupervised, but restricted intermediate license stage), or a true three-stage GDL program with one or two restrictions during the intermediate licensing stage.

D. Studies of GDL Programs

1. Single-State Studies of GDL

The overwhelming majority of single-state (i.e., one state or province) GDL studies conducted in the U.S., Canada, and New Zealand have found positive safety effects (Hedlund & Compton, 2005; Mayhew et al., 2005; Senserrick & Haworth, 2005; Shope, 2007). Of those studies showing a positive effect associated with GDL programs, the estimates of crash reductions range from 20–40% (Shope, 2007; Shope & Molnar, 2003). Studies of GDL programs have differed greatly in the age groups studied (e.g., only 16 year old drivers vs. 15–17 year olds combined), length of follow-up (ranging from months to several years), types of crashes examined (e.g., fatal/injury, all crashes, at-fault only, etc.), specific crash metrics used (e.g., unadjusted counts, per capita rates, etc.), methodologies used to adjust for trends and other historical events (ranging from no adjustment to complex time series analyses), and statistical methods used to estimate effects (ranging from simple differences in crash counts to complex statistical modeling). Furthermore, the baseline crash rates to which GDL effects are compared differ across studies because some states went from having only a one-stage teen driver licensing system to a three-stage GDL-based program, whereas others had two-stage teen driver licensing systems (e.g., mandatory learner permit periods or nighttime driving restrictions) prior to implementing GDL. Finally, the components and calibrations of each state's GDL program also differ, which makes it unclear how appropriate it is to generalize results showing a program to be effective in one state to a differently-configured GDL program in another state.

One other relevant issue is that not much is known about which specific components of GDL programs are the most effective, or what calibrations of the components are associated with the largest crash reductions (e.g., what is the best length for a learner permit holding period or start time for a nighttime driving restriction) beyond what seems intuitive (e.g., longer holding periods and earlier restriction start times would be logically expected to be associated with larger crash reductions). In most cases, single-state studies of GDL programs are just that: studies of the programs as a whole without an attempt to disentangle which specific components of the licensing systems are most strongly associated with reductions in young teen crash rates. There are some instances in which researchers have attempted to show that specific components were effective by analyzing crash series that would be most strongly influenced by nighttime or passenger restrictions (i.e., crashes during the restricted nighttime driving hours or crashes in which the teen driver was transporting a teen passenger; e.g., Foss, Feaganes, & Rodgman, 2001; Rice, Peek-Asa, & Kraus, 2004), or by analyzing proportional incidence rates of these crashes, which attempt to remove overall GDL program effects prior to estimating the effects specifically associated with the restrictions (i.e., percentage of total crashes occurring at night or percentage of total crashes with teen passengers; e.g., Masten & Hagge, 2004). In a few instances researchers have been able to identify states that made single-component changes to their teen driver licensing systems (e.g., Agent, Steenbergen, Pigman, Kidd, McCoy, & Pollack, 1998; Ulmer, Preusser, Williams, Ferguson, & Farmer, 2000), which allowed them to estimate the effect size for an individual GDL component without the inherent confounding resulting from making multiple program changes contemporaneously.

However, none of the methods just discussed allow researchers to make comparisons among the range of variations in how GDL components are calibrated. For example, it is not possible to empirically determine based on a single-state study whether nighttime driving restrictions should start at 10:00 pm, 11:00 pm, midnight, or 1:00 am to achieve the largest crash reductions, or whether it is more effective to have a learner permit holding period last for 1, 3, 6, 9, or 12 months. It is unlikely that more restrictive calibrations (e.g., restricting teens completely from transporting teen passengers rather than allowing one) are always associated with larger reductions either; at some point if components are too restrictive they are likely to be largely ignored (Goodwin & Foss, 2004; Goodwin, Wells, Foss, & Williams, 2006). Comparisons among the different calibrations of each GDL component would be useful for establishing the specifications associated with the greatest crash reductions. The only way to do this would be to include multiple states in the same analysis to capitalize on both within-state and between-state variability in teen driver licensing systems over time.

However, because single-component changes to GDL programs are rare, such an analysis would require that a large number of states be included to help insure that the effects associated with other components implemented at the same time could be estimated and statistically controlled.

2. Multiple-State Studies of GDL

Given the differences across states' GDL program components and calibrations, and the methodological differences across the studies, it does not seem appropriate to estimate an average effect associated with GDL combined across single-state studies as might be done in a meta-analysis. Possibly because of these limitations, several different attempts to summarize effects associated with GDL programs across the U.S. have recently been published (Chen, Baker, & Li, 2006; Dee, Grabowski, & Morrisey, 2005; McCartt, Teoh, Fields, Braitman, & Hellinga, 2010). These studies attempted to derive a combined measure of average GDL program effect across multiple U.S. states by using a single national data source of fatal crash involvements, the Fatality Analysis Reporting System (FARS). Across all U.S. GDL programs Dee, Grabowski, and Morrisey (2005) estimated that there was a 6–10% reduction in 15–17-year-old crash fatalities, and Chen, Baker, and Li (2006) estimated that there was an 11% reduction in the incidence of 16-year-old driver involvements in fatal crashes, associated with GDL. However, neither study successfully disentangled the specific GDL components associated with crash reductions.

McCartt, Teoh, Fields, Braitman, & Hellinga (2010) did attempt to calculate both overall effects associated with GDL programs and the effect sizes associated with individual

GDL components. While they did not present a single estimate of all GDL programs combined, they did find that teen driver licensing systems rated as "Good" according to the IIHS' teen licensing system quality rating scheme were associated with a 44% reduction in the incidence of 15-year-old driver fatal crash involvements, a 41% reduction among 16 year olds, a 19% reduction among 17 year olds, and directional, but not statistically reliable, reductions of 4% and 3% among 18 and 19 year olds, respectively. Licensing systems with lower IIHS licensing program quality ratings were generally associated with smaller reductions or in some cases increases in fatal crash incidence. In terms of GDL program core components, they found that only nighttime driving restrictions and passenger restrictions were associated with reductions in driver fatal crash incidence for each age group from 15–17 years. Learner stage entry ages and unsupervised licensing ages were associated with lower incidence for 15 and 16 year olds, but not for 17 year olds. Learner permit holding periods and required hours of supervised driving practice were not associated with lower driver fatal crash incidence for any of the age groups.

Another recent study attempted to assess the average effects associated with GDL programs and individual GDL components combined across U.S. states and Canadian provinces (Vanlaar, Mayhew, Marcoux, Wets, Brijs, & Shope, 2009). They found a reliable 19% decrease in 16-year-old driver fatalities, no change for 17 year olds, and directional but unreliable increases of 8% and 6% for 18 and 19 year olds, respectively, associated with implementing GDL programs in North America. They further attempted to determine which individual GDL components (e.g., learner permit holding periods and nighttime driving restrictions) were most strongly associated with the observed changes in teen driver fatal crash incidence, which will be discussed in more detail later.

It is noteworthy that the effect estimates from multi-state studies of GDL programs, with the exception of those from McCartt et al. (2010), are smaller than those typically reported from single-state studies of GDL programs. One possible explanation for this discrepancy is that it reflects a "file drawer" problem, meaning that single-state studies with smaller effect sizes tend to not be published in the peer-reviewed literature. Alternatively, the smaller estimates for multi-state studies might be due to their cross-sectional nature (Hauer, 2010). There are certainly other reasons that might explain the discrepant effect sizes from the two types of studies; the point here is to highlight this observation. Towards the goal of better understanding the methods and problems of existing multi-state GDL studies, each of the peer-reviewed multi-state studies discussed briefly earlier is presented in detail and critiqued in the following sections.

a. Dee, Grabowski, and Morrisey (2005) U.S. GDL Study

The first nationwide study of GDL programs by Dee, Grabowski, and Morrisey (2005) involved an analysis of 1992–2002 (11 years) annual driver, passenger, and pedestrian fatalities from FARS for the 48 continental U.S. states (see also Morrisey, Grabowski, Dee, & Campbell, 2006). The fatalities were categorized into age groups of 15–17, 18–20, 21–23, and 24–26 for analysis purposes. Log-transformed population counts for each age group were used to adjust for exposure.

Dee et al. (2005) statistically adjusted for several factors to account for confounding effects associated with changes in other highway-related laws in each state (e.g., speed limit changes, seatbelt laws, and alcohol-related laws), along with the effects associated with macroeconomic forces by using state-specific annual unemployment. The actual statistical model used was conditional maximum likelihood negative binomial regression. Indicator variables representing the states were used in the analyses to account for average differences in fatalities across the states, and fixed-effects year variables were used to account for trends in fatalities. The yearly trend and state indicator variables were allowed to differ by aggregated age group, and in some models the trend was also allowed to vary by state.

Dee et al. (2005) conducted two different and complementary types of analyses. In one set of analyses referred to as the "differences-in-differences approach," the expected changes over time in 15–17-year-old fatalities for GDL states were modeled using changes in 15–17-year-old fatalities in states that did not have GDL programs. That is, the fatality rates of non-GDL states were used as the expected values for the GDL states in the absence of GDL (i.e., the counterfactual). In the other set of analyses referred to as the "differences-in-differences-in-differences framework," the changes in crash fatalities of adults from GDL states were used as the counterfactual expected changes for teen fatality rates in those same states in the absence of GDL. In all analyses the GDL effect measure represents the average pre-post change in 15–17-year-old crash fatalities in GDL states relative to the change observed in the counterfactual group (i.e., either teens in non-GDL states or adults in GDL states).

Across all U.S. states, Dee et al. (2005) estimated that implementing GDL programs was associated with a 10% average reduction in 15–17-year-old crash fatalities based on differences-in-differences Model 4 results that allowed for state-specific trends and used changes in 15–17-year-old crash fatalities in non-GDL states as the counterfactual expectation. No reliable changes in crash fatalities associated with GDL were found for any of the adult age groups. The estimated reduction in 15–17-year-old crash fatalities associated with GDL was 6% based on the differences-in-differences-in-differences approach in which adult fatal crash fatalities from the same GDL states were used as the counterfactual expectation (based on Model 5 in which all adult age groups are included).

Dee et al. (2005) did not conduct analyses estimating the effects associated with specific program components (e.g., effects associated with longer versus shorter learner permit holding periods or early versus late nighttime driving restriction start times). Instead the issue of heterogeneity in GDL programs across states was approached at a macro level by using IIHS' teen licensing program quality rating taxonomy (IIHS, 2009b). Using this rating system, each state's GDL program in a particular year was classified as "Good," "Fair," "Marginal," or "Poor" based on the configuration and calibration of its teen licensing components relative to what IIHS considers to be an optimal program. They found that crash fatality reductions for 15–17 year olds were the largest for programs rated as "Good" (19%), and smaller for those rated as "Fair" (6%) or "Marginal" (5%), relative to those rated as "Poor." The overall conclusions from the study were that GDL programs were effective for reducing teen fatalities and that the most stringent GDL programs appeared to be even more effective. However, it was not possible to determine the specific program components and calibrations associated with these reductions because IIHS quality ratings were used as a surrogate rather than coding and analyzing the specific types of program components included in each GDL program. In a related paper (Morrisey, Grabowski, Dee, & Campbell, 2006) the authors attempted to demonstrate that nighttime and passenger restrictions were effective GDL components by presenting how variations in IIHS teen licensing program quality ratings were associated with daytime and nighttime 15–17-year-old driver fatalities, 15–17-year-old driver fatalities when transporting other teens, and fatalities among teen passengers. The methodology used in that study was essentially the same as that used by Dee et al. (2005).

Dee et al. (2005) adjusted for confounding resulting from changes in other highway-related laws, average differences between state fatal crash rates, state- and age-specific trends (in some analyses), and macroeconomic influences. The contemporaneous crash fatalities of teens in non-GDL states or adults in GDL states were used as counterfactual expectations in an attempt to control for other unmeasured historical factors. Analyses were also performed showing no effects associated with GDL for adult drivers to bolster making causal inferences about GDL program effects. While the approach of using adults as a counterfactual would be expected to model some historical variability in teen crash rates (and is presumably why indicator variables were not included in those models for changes in other highway-related laws that affected all drivers), the adults-as-counterfactual method assumes that changes in adult crash fatalities are reasonable expected values for changes in teen crash fatalities, which may not be true. Different combinations of adult counterfactuals were used as a check of robustness, but evidence was not presented that any single adult age group or combination would be a reasonable expectation for what the changes in teen crash fatality rates would have been in the absence of the GDL programs. This is a problematic assumption given that crash rates vary widely by age and those for adult drivers are different from those for teens (e.g., Figure 1). Although the adult and teen rates are different overall, time-period-to-time-period variability in the adult rates may coincide with variability in the teen rates due to shared historical influences. This suggests that modeling adult rates as time-varying covariates rather than as counterfactuals may be a more effective strategy for controlling unmeasured historical confounding factors (e.g., changes in roadway environments, traffic enforcement, and fuel prices).

Dee et al. (2005) did not account for time-dependent correlation (autocorrelation) resulting from the geodemographic clustering of the crash fatality rates (i.e., repeated measurements of age × state crash fatality rates over time). Instead it was argued that the relatively short study time period (11 years) would reduce the likelihood that autocorrelation would bias the estimates. If the repeated measurements of age-group fatalities within each state are serially (time) dependent, failing to adjust the variances for this clustering would result in confidence intervals that imply greater precision than is actually warranted. The larger implication of not adjusting for autocorrelation would be to bias the analyses towards finding reliable effects associated with GDL programs.

Another problem is that Dee et al. (2005) combined 15–17 year olds into a single group for the analyses. Only 10 U.S. states licensed 15 year olds to drive unsupervised over the past 2 decades (FHWA, 1986). Hence, including 15 year olds added little to the fatality counts. In states where 15 year olds are not allowed to drive legally, the crashes among such drivers also tend to be atypical. For example, alcohol use among 15-year-old drivers involved in crashes in North Carolina—where 15 year olds are not allowed to drive legally—is consistently higher than among 16-year-old crash-involved drivers. Furthermore, the age grouping presupposes that any GDL program effects are homogenous across all teen age groups, and there is evidence that the effects associated with GDL vary for 16 and 17 year olds (e.g., Ulmer et al., 2000; Rice et al., 2004).

Finally, Dee et al.'s (2005) overall GDL program effect estimates were based on lumping all GDL-like teen driver licensing systems into a single group, whether or not they were true three-stage GDL programs with meaningful learner permit holding periods and non-trivial license restrictions during the intermediate licensing stages. While the analyses using IIHS licensing program quality ratings attempt to remedy this problem, even those estimates of GDL program effects are likely biased downward by the inclusion of pseudo-GDL programs (e.g., Arkansas, which did not have a true three-stage GDL program until 2009 yet is coded as having a GDL program effective in July 2002).

b. Chen, Baker, and Li (2006) U.S. GDL Study

The second multi-state study of GDL programs was conducted by Chen, Baker, and Li (2006) using negative binomial regression models to analyze quarterly FARS data for drivers involved in fatal crashes from 1994–2004 (11 years) for 43 continental U.S. states. Excluded were states that made multiple changes to their teen driver licensing systems during the study time period. Separate models were calculated for 16, 20–24, and 25–29 year olds.

Excluded from the analyses were 17–19 year olds. The adult crash rates were not used as time-varying covariates or as counterfactuals to model the expected changes in 16-year-old driver fatal crash involvements in the absence of GDL. Rather, the purpose of modeling the crash rates of adult drivers was to indirectly support the argument that any changes seen in the 16-year-old's crash rates were more likely due to GDL, given that no comparable changes in the crash rates for these older age groups were found. The models included parameters for trend (continuous year variable), seasonality (quarter indicator variables), and average differences between the driver fatal crash incidences of the states (state indicator variables). However, these variables were not parameterized as interaction terms in the models, so trends and seasonality were assumed to be the same across all included states. Generalized estimating equations (GEEs) were used to account for autocorrelation among the repeated measurements of fatal crash rates over time for each age group in each state (geodemographic clustering).

Chen et al. (2006) excluded from the analyses a full year of data immediately before and after each state's GDL program was implemented or substantially changed (i.e., 4 quarters before and 4 quarters after implementation). The reason for doing so was to remove temporary effects associated with transitioning teen drivers into the GDL program in each state. For example, before implementing a GDL program, some states experienced an influx of teen licensees who applied earlier for licensure to avoid being subject to the GDL program (e.g., Foss et al., 2001; Masten & Hagge, 2004). The periods immediately before and following GDL implementation may have somewhat higher teen crash rates because of the influx of early licensees seeking to avoid the program and the resulting increased driving exposure. The latter quarters were also excluded because due to grandfathering during implementation it could have taken a year or longer before all 16 year olds in a state were subject to the GDL program following its implementation.

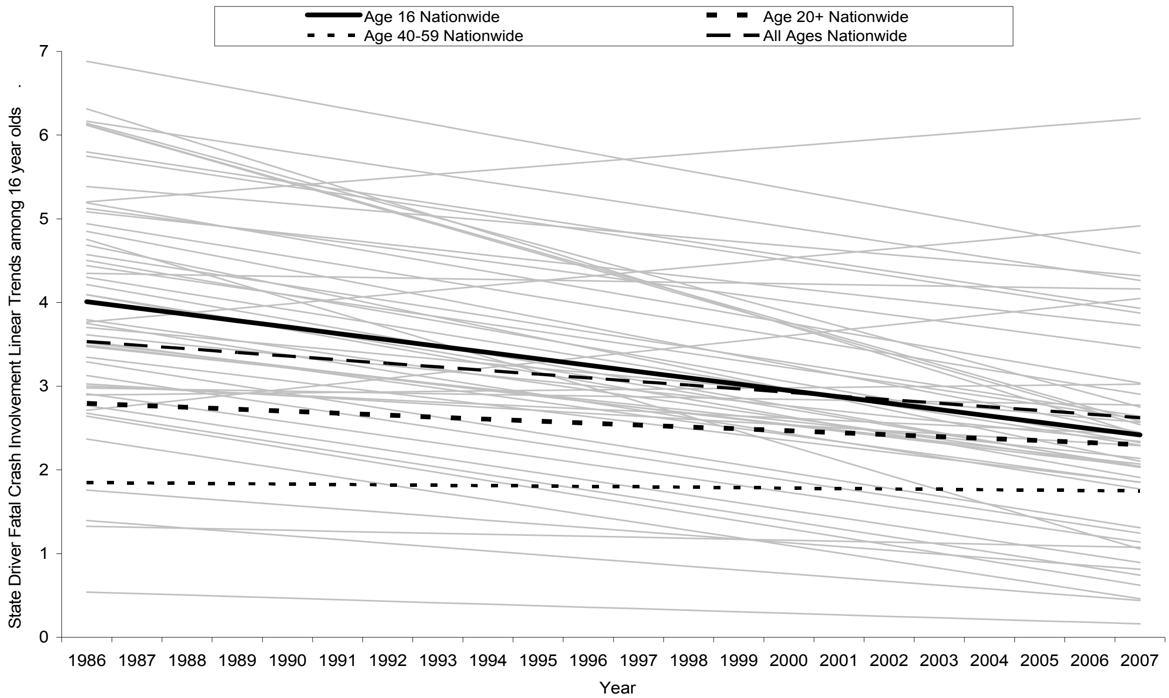
Combined across all included states, Chen et al. (2006) estimated that there was about an 11% reduction in the incidence of 16-year-old drivers involved in fatal crashes associated with implementing GDL programs. No reliable reductions associated with GDL programs were found in the crash rates for the older age groups (20–24 and 25–29).

To better characterize how the effect sizes varied across GDL programs, Chen et al. (2006) used two different approaches. First, the variation in effect sizes as a function of the total number of GDL program core components (out of seven) in effect during each quarter was presented. Because the calibration of program components also varies between states (e.g., the learner permit holding periods vary across states from 7 days to 12 months), the seven components were first dichotomized into crude categories and then each state quarter was coded as having or not having a particular GDL component in effect. For example, using this coding strategy a state was coded as having a learner-permit holding period only if it had one that was at least 3 months long and a state was coded as requiring supervised driving hours only if at least 30 hours of supervised driving were required. A state was coded as having nighttime or passenger restriction if it had any type of either of them, regardless of start time, the number of passengers allowed, or the length of time each was in effect. While having one or more GDL components of any type in effect (based on the dichotomous definitions) was directionally consistent with reductions in driver fatal crash involvements for 16 year olds and both adult groups, the estimated reductions for 16 year olds were reliably estimated only for programs with five or more components in effect. However, some reliable decreases in driver fatal crash involvements were also found for 20–24 year olds, suggesting that some of the associations were likely spurious.

The second approach Chen et al. (2006) used to characterize how the effect sizes varied across GDL programs was to present the variation in effect sizes as a function of selected combinations of dichotomously-coded GDL components. However, for some unexplained reason specific combinations of only four of the seven GDL core components (learner permit minimum holding periods, required hours of supervised driving practice, nighttime driving restrictions, and passenger restrictions) were included, and only an overall combined estimate for each of the remaining components (minimum ages for obtaining a learner permit, obtaining an intermediate license, and obtaining a full license) were provided. Based on this approach, it was concluded that only GDL programs having at least a minimum learner permit holding period and a nighttime driving restriction, along with a passenger restriction and/or a supervised driving hours requirement, were reliably associated with lower 16-year-old driver fatal crash incidence (ranging from a 16-21% reduction).

The Chen et al. (2006) multi-state study of GDL programs has a number of analytical and design flaws that likely resulted in GDL effect estimates that are confounded by state-specific trends, seasonality, changes in other highway-related laws, and unmeasured historical factors, which makes it difficult to place much faith in the validity of the effect estimates. While adjustments were made for average differences in fatal crash rates between states, the parameters included to model trends and seasonality were not used in interaction terms with state, which assumes that trends and seasonal cycles are the same across all states. This is a serious error because trends and seasonality in driver fatal crash involvements actually do vary considerably across states, yet the adjustment method only provided a single average nationwide adjustment for each of these potentially confounding factors. For illustration purposes, Figure 4 shows annual driver fatal crash involvement linear regression lines for 16 and 17 year olds for each U.S. state from 1986–2007 (light gray lines), along with nationwide trends for selected groups of adults, 16 year olds, 17 year olds, and all ages combined, for purposes of illustrating the wide-ranging differences among states in driver fatal crash involvement trends.

The plots suggest that there may be differences among U.S. states in the fatal crash rates of 16 and 17 year olds (which was adjusted for in the model using state indicator variables), that the long-term linear trends for each age group may differ across U.S. states (some even appear to be increasing while others are decreasing), and that the trends for 16 and 17 year olds may differ from each other. These differences were found to represent meaningful variation when developing the models for the present study in that reliable differences were found among state crash rates and linear trends. Furthermore, the state-specific crash rates and linear trends were found to reliably differ across the teen age groups included in the present study. Hence, it is not possible that a single trend parameter for 16 year olds could have adjusted for the heterogeneous trends across states that are illustrated in the figure. It is also likely that seasonal fluctuations in fatal crash involvements may differ across states given the large differences in driving environments and weather. Hence, Chen et al.'s (2006) GDL effect estimates are probably confounded by residual trend and seasonality, because these parameters were not allowed to vary by state.



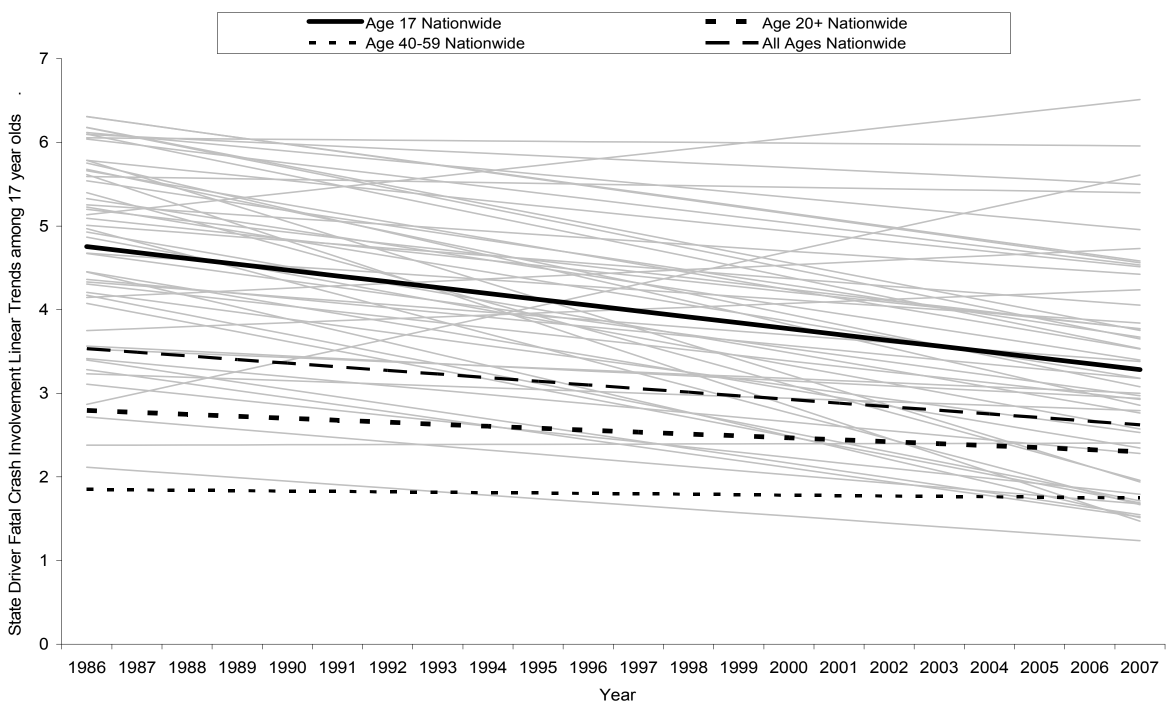


Figure 4. Linear driver fatal crash involvement trends for 16 year olds (upper) and 17 year olds (lower) in each U.S. state (light gray lines), along with nationwide trends for selected groups of adults, 16 year olds, 17 year olds, and all ages combined, 1986–2007 (lines represent the long-term linear trends in fatal crash involvement rates for each state).

Another problematic method in Chen et al.'s (2006) study was excluding a year of data both before and after each GDL program was implemented. This exclusion could have further compromised the parameter estimates for seasonality and trend because it reduced the numbers of data points available to estimate these effects and created temporal breaks in the series. That is, data points were dropped in the middle of temporally-ordered series, yet estimates were made for long-term trends and seasonality (though these parameters are even more problematic because they were not allowed to vary by state). In addition, the effects associated with mandatory learner permit holding periods and some other GDL components would have occurred immediately following the implementation of the GDL programs, and the method could result in inaccurate estimates of the effects associated with these components. The exclusion of data in this manner may seem logically appealing as a means to reduce certain potential biases associated with transition effects, but it also introduces an analytical flaw that may have reduced the ability to accurately model nuisance variables and program effects.

In addition to the problems described above, Chen et al. (2006) also did not control for state-to-state variability in teen driver fatal crash involvements associated with changes in other highway-related laws, economic conditions, traffic enforcement, weather conditions, or other unmeasured historical factors that varied over time. The prior study by Dee et al. (2005) included variables in the analyses to remove confounding effects associated with state-specific changes in laws regarding mandatory seat belt use, maximum allowable speed limits, minimum legal drinking ages, zero tolerance alcohol limits for persons under age 21, maximum blood alcohol concentrations, and administrative license suspension for drunk drivers. Many of these other highway-related law changes are known to be associated with fatal crash involvement, all states made changes to at least three of these laws, and the majority of states made changes to almost all of them, yet these confounding effects were not modeled by Chen et al. (2006). Neither were proxies used in an attempt to model the effects associated with these factors, such as by using the state-specific crash rates for the adult age groups as covariates or as counterfactual expectations for the 16-year-old crash rates in the absence of GDL (though is potentially problematic for other reasons). Instead, the two adult age groups were analyzed in separate models to support the hypothesis that GDL is the cause for any observed changes in 16-year-old crash rates, given the absence of such changes in the rates of the adult drivers. Failing to control for changes in other highway-related laws and state-specific historical variability is a serious analytical shortcoming, particularly in light of the fact that trends and seasonality were also not adjusted conditional on state.

Other problems with the Chen et al. (2006) study include having too few pre-GDL data points for some states (the first GDL program was implemented in July 1996) to be able to model trends and seasonality in teen fatal crash involvement rates without the estimates being confounded by GDL program implementation, and grouping all GDL programs together to obtain an overall GDL effect estimate, regardless of whether the programs had meaningful learner permit holding periods and non-trivial license restrictions during the intermediate licensing stages. The latter likely ignores an important source of heterogeneity in GDL effect sizes that is not entirely remedied by the follow-up analyses comparing counts and dichotomous combinations of included GDL components. Finally, fatal crash data for 17, 18, and 19 year olds were excluded from the study, so it provided no evidence regarding how GDL programs might affect older teens.

While Chen et al. (2006) attempted to disentangle the specific GDL components associated with 16-year-old fatal crash reductions, the method did not provide estimates for each specific GDL core component adjusted for all other GDL components, nor did it provide separate estimates for the three age-related GDL core components. In addition, GDL program components were dichotomized as present/absent, without taking in account the total range of specific calibrations. In reality the program component calibrations vary along a continuum (e.g., learner permit holding periods range from 7 days to 12 months across U.S. states), which is not distinguished using this crude strategy, so it is not possible to determine from the analyses whether particular calibrations are better than others. While the approach is interesting for possibly determining how certain combinations of components work together contextually, it did not result in learning the specific components associated with crash reductions, nor how each might be optimally calibrated.

c. Vanlaar, Mayhew, Marcoux, Wets, Brijs, and Shope (2009) North American GDL Study

The next study that attempted to characterize the overall effects associated with GDL programs, and which also aimed to determine which program components were associated with differences in GDL effectiveness, was completed by Vanlaar, Mayhew, Marcoux, Wets, Brijs, and Shope (2009). The authors used 1992–2006 (15 years) driver fatalities for 47 U.S. states from FARS and for 11 Canadian provinces from Transport Canada's Traffic Accident

Information Database to calculate pre-post GDL rate ratios separately for 16, 17, 18, 19, and 25–54 year olds in each state or province. States/provinces were excluded if they did not have a GDL program, or did not have 2 years of post-implementation data available by the end of 2006. The pre-implementation period was defined as the 12-month interval ending 1 year prior to each GDL program's implementation, and the post-implementation period was defined as the 12-month period starting 1-year after implementation. The exclusion of data from the year immediately before and after each GDL program was intended, similar to Chen et al. (2006), to avoid any effects associated with transitioning teens into the GDL programs.

The effect measures Vanlaar et al. (2009) analyzed were age-group specific pre-post adjusted rate ratios of per population driver fatality rates in each state/province. That is, for each state or province the pre-GDL per capita fatality rate was calculated and divided by the post-GDL per capita fatality rate (based on the 12-month pre-post time periods described above). These rate ratios were then divided by the contemporaneous rate ratios for 25–54-year-old drivers in the same state/province to create adjusted driver fatality rate ratios (i.e., the teen rate ratios were standardized to those for adults). More than one adjusted rate ratio was included from some states/provinces when additional legislative changes were made to the teen driver licensing systems such that there were 78 adjusted rate ratios for each teen age group rather than 58 (as might be expected given the inclusion of 47 U.S. states and 11 Canadian provinces). The adjusted rate ratios were then combined using meta-analysis techniques, including inverse-variance weighting procedures, to obtain pooled estimates of GDL program effects for each age group. The purpose of weighting the rate ratios was to account for the fact that those with smaller variances (i.e., estimates for states or provinces with larger populations of teen drivers) are more stable, and therefore should contribute more to the overall combined estimates of GDL program effects.

Combined across the U.S. states and Canadian provinces, Vanlaar et al. (2009) estimated that GDL programs were reliably associated with a 19% reduction in 16-year-old driver fatality rates, but no reliable change (0%) in 17-year-old driver fatality rates. The results were also consistent, though not reliably so, with increases of 8% and 6% in 18-year-old and 19-year-old driver fatality rates, respectively. For reasons that will soon be obvious, it is important to emphasize that these estimates are based on straightforward calculations of weighted averages of the adjusted driver fatality rate ratios, rather than being based on complex statistical modeling.

Vanlaar et al. (2009) also performed complex statistical analyses to determine whether the weighted average adjusted driver fatality rate ratios for 16, 18, and 19 year olds varied as a function of the effective date of the GDL implementation (continuous year), IIHS ratings of teen driver licensing program quality (good, fair, marginal, or poor), country (U.S. vs. Canada), and 20 factors describing the specific GDL components and calibrations of each GDL program. Included in these 20 GDL component/calibration variables were six of the seven GDL core components: (a) minimum learner stage entry age (continuous years of age from 14–16 years); (b) learner permit minimum holding period (continuous 0–12 months); (c) minimum required hours of supervised driving practice (continuous 0–60 hours); (d) minimum intermediate licensing age (continuous from 14.5–17 years); (e) length of nighttime driving restriction during the intermediate licensing stage (from 0–10 hours); and (f) passenger driving restriction during the intermediate licensing stage (yes vs. no). The only GDL core component not included in the analyses was the minimum age at which the teens could get an unrestricted license. In addition to these six GDL core components, the analyses included 14 variables representing other program restrictions, requirements, and exceptions. Several variables were related to the GDL program core components, such as whether there was an exception to the nighttime driving restriction for work purposes or to the passenger restriction if the passengers were family members. The analyses of GDL program components/calibrations were based on only 48 effect sizes (for each age group) rather than the full 78 because of missing data for the coded variables. This loss of almost 40% of the data points is problematic because it limits the extent to which the findings from the component analyses inform those of overall GDL program effects because the analyses are not based on the same samples of states/provinces. Furthermore, it is not stated which states or provinces were excluded from the component analyses because of missing information or whether the excluded states/provinces might have differed in some meaningful way from those retained for the analyses.

The results of Vanlaar et al.'s (2009) GDL component/calibration analyses for 16 year olds indicated that the GDL effect sizes for this age group differed as a function of only two of the coded factors. The first was whether there was a passenger restriction during the intermediate licensing stage (coded as yes/no), which is one of the GDL core components. The results suggest that GDL programs with a passenger restriction during the intermediate licensing stage are associated with 88% lower 16-year-old adjusted driver fatality rates compared to states/provinces without such a restriction. While the size of this estimated reduction is difficult to believe, it pales in comparison to the size of the estimated effect reported for allowing intermediate licensing stage passenger restrictions to be waived if the passengers are family members (coded as yes/no). Specifically, GDL programs with a family-member exception to the intermediate licensing stage passenger restriction were found to be associated with 728% higher 16-year-old adjusted driver fatality rates relative to states/provinces that do not have such an exception or that do not have a passenger restriction at all. None of the other coded components, calibrations, ratings of program quality, or other factors were found to be reliably associated with variations in the adjusted driver fatality rate ratios for 16 year olds.

Vanlaar et al. (2009) did not conduct analyses of GDL components/calibrations for 17 year olds because the overall GDL program weighted driver fatality rate ratio for this age group was essentially 1.00 (no effect). The GDL component/calibration analyses for 18 year olds indicated that the adjusted rate ratios for this age group varied as a function of only one of the coded factors, which was whether the GDL program included mandatory driver education in the learner stage (coded as yes/no). Specifically, GDL programs requiring driver education in the learner stage were found to be associated with 34% lower 18-year-old adjusted driver fatality rates relative to states/provinces without driver education requirements in the learner stage.

With regard to the GDL component/calibration analyses for 19 year olds, Vanlaar et al. (2009) found that the adjusted driver fatality rate ratios for this age group varied as a function of five of the coded factors. One of these factors was the length (in hours) of any nighttime driving restriction in the *learner* stage of the GDL program (not the intermediate licensing stage, which is a GDL core component). States and provinces with longer nighttime driving restrictions in the learner stage of the GDL programs were found to have *higher* 19-year-old driver fatality rates relative to states/provinces with no nighttime driving restriction in the learner stage. Specifically, each additional hour of restricted driving time was found to be associated with about an 11% increase in 19-year-old adjusted driver fatality rates compared to having no learner stage nighttime driving restriction. The other results from the 19-year-old GDL component/calibration analysis are also questionable. For example, the adjusted driver fatality rate of Canadian 19 year olds was found to be 1,229% (over 12 times) higher than that for 19 year olds in U.S. states. In addition, states and provinces with exceptions to intermediate licensing stage nighttime driving restrictions for employment purposes were found to have 5,109% higher 19-year-old driver fatality rates. States and provinces with GDL programs requiring mandatory driver education during the *intermediate* licensing stage were found to have 111% higher 19-year-old driver fatality rates, and those requiring an exit test to graduate from the intermediate licensing stage were found to have 98% higher 19-year-old driver fatality rates.

One of the positives of Vanlaar et al.'s (2009) study is that the effect sizes were weighted by the inverse of their variances, which would help achieve unbiased combined effect estimates. Another strength is that the method used in the study rigorously controlled for average differences in crash rates across states/provinces by creating within-state/province adjusted driver fatality rate ratios. Whereas the prior multi-state GDL studies attempted to control for average differences among states' crash rates through modeling (i.e., state indicator variables), the method used by Vanlaar et al. (2009) likely provided even better control for these differences. Another positive is the fact that all teens from ages 16–19 were included in the study and each individual age group was analyzed separately (i.e., teens were not combined into larger age groups), which allowed for the possibility that GDL program effects vary for teens of different ages (which is exactly what was found).

One of the most serious problems with the methods used by Vanlaar et al. (2009) is that the validity of the resulting effect estimates depends to a large extent on the degree to which using changes in adult driver fatality rates as the counterfactual expectation actually removed the confounding effects associated with trends, seasonality, changes in other highway-related laws, and other unmeasured historical factors (e.g., fuel prices). Specifically, recall that adjusted driver fatality rate ratios were created by dividing the pre-post GDL rate ratios for teens by the contemporaneous pre-post rate ratios for 25–54 year olds in each state/province. The assumption of this method is that adults in this age group would not be affected by the GDL programs and so changes in adult crash rates represent a good counterfactual for what would have been expected to occur for each teen age group in the absence of the GDL programs. While some single-state studies of GDL programs have also used this method with the same intention (e.g., Foss et al., 2001; Rice et al., 2004), there is no evidence that it actually removes all the confounding by these factors, and there is ample evidence that it probably does not.

The adults-as-counterfactual method used by Vanlaar et al. (2009) assumes that pre-post GDL changes in adult driver fatality rates in each state/province embody all the combined effects associated with trends, seasonality, changes in other highway-related laws, and numerous other unmeasured historical factors that would have affected teen driver fatality rates in those states/provinces in the absence of GDL. Furthermore, it assumes that the magnitude of the effects of these confounding factors would have been the same for adults and teens. Among other things for this method to work, the pre-GDL trends in fatal crashes for the adults in each state/province must be the same as those for each teen age group. This can easily be shown to not be true for all U.S. states. For example, the California GDL program was implemented in July 1998, so Figure 5 shows the California 1986–1997 (pre-GDL) annual per capita driver fatality rates for 16, 17, 18, and 19 year olds, along with those for selected combinations of adult age groups that might be used as counterfactuals for the teens per the adults-as-counterfactual method.

It can clearly be seen in the figure that the trends in driver fatal crash involvements for the teen age groups are different than those for the adult age groups. This is particularly evident from 1996–1997, which would have encompassed the pre-GDL period used for the California rate ratio in their study. Hence, Vanlaar et al.'s (2009) method of standardizing the changes in teen rate ratios to those observed for 25–54 year olds would not have removed all confounding in the California teen rate ratios due to trends, because the adult and teen trends were different. This is likely also true for other North American states/provinces where it is sometimes the case that the pre-GDL teen and adult driver fatal crash trends moved in opposite directions.

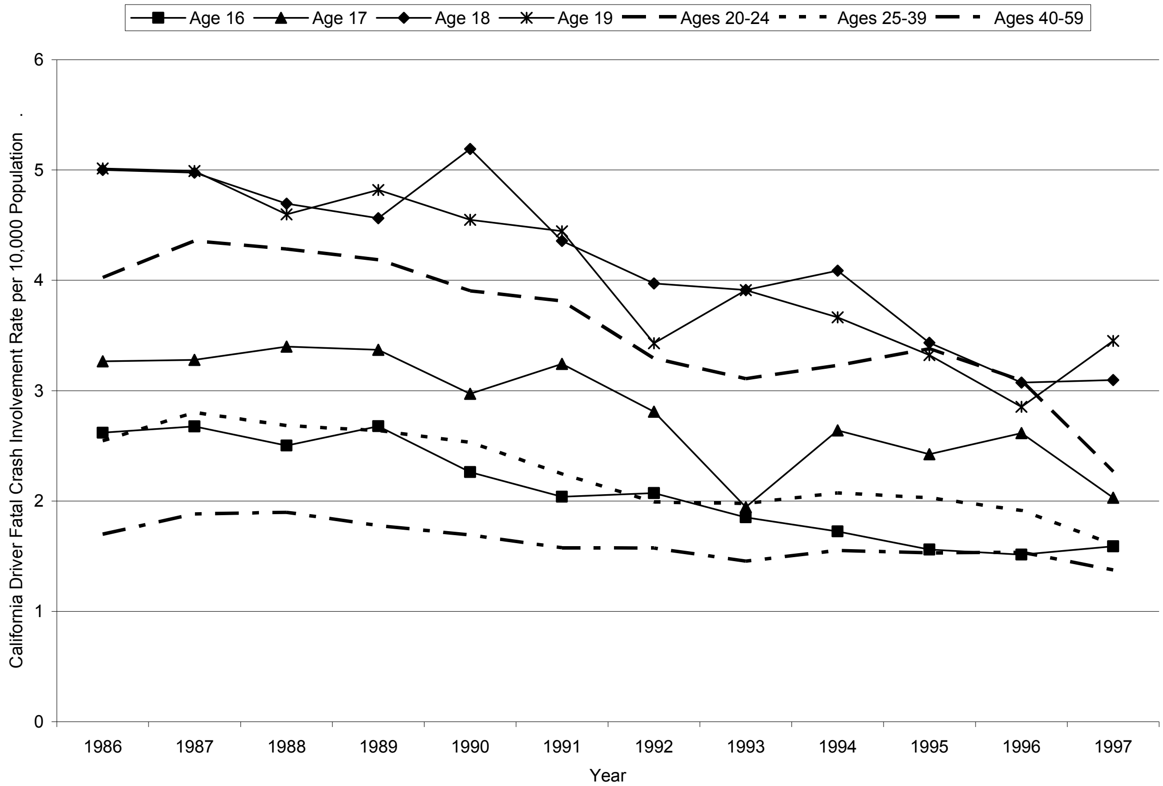


Figure 5. Annual California driver fatal crash involvement rates for 16, 17, 18, and 19 year olds, along with those for selected combinations of adults, 1986–1997 (pre-GDL).

Because Vanlaar et al. (2009) analyzed dichotomous (pre vs. post) outcome data rather than using continuous data (e.g., using multiple snapshots pre vs. post), it was not possible to use another approach to adjust for trends in teen fatal crash involvements. Similar to Chen et al. (2006), 12 months of time were excluded immediately before and after each GDL program was implemented (to avoid transition effects), which would exacerbate the effects of any residual trend by comparing data points that are temporally further apart. A superior approach would have been to use continuous outcome data and an analytic method that inherently models trends (e.g., ARIMA interrupted time series analysis) to obtain valid effect sizes for each state/province that would then be combined using weighted meta-analysis techniques, as has been recently done in a series of comprehensive studies of U.S. alcohol laws (Wagenaar & Maldonado-Molina, 2007; Wagenaar, Maldonado-Molina, Erickson, Ma, Tobler, & Komro, 2007; Wagenaar, Maldonado-Molina, Ma, Tobler, & Komro, 2007). Because of the reasons above, it seems likely that the overall GDL program effect estimates are confounded by residual trends in teen driver fatality rates.

Vanlaar et al.'s (2009) method of using adults as a counterfactuals also assumes that any effects associated with changes in other highway-related laws (e.g., seat belt laws, speed limits, and alcohol-related driving laws) and unmeasured historical factors (e.g., fuel prices and macroeconomic forces) would be the same for teens as for adult drivers. This is a strong assumption and there is empirical evidence of age-specific differences in effect sizes suggesting that it is not correct for at least some of these confounders (e.g., admin *per se* laws, primary enforcement seat belt laws, maximum speed limits, fuel prices, and unemployment; Grabowski & Morrisey, 2004). The method also would not remove the confounding effects associated with other highway-related law changes aimed specifically at teen drivers, such those of minimal legal drinking ages and zero-tolerance laws, given that these laws have been shown to have larger effects on teens than on adult drivers (e.g., McCartt, Hellinga, & Kirley, 2010; Villaveces, Cummings, Koepsell, Rivara, Lumley, & Moffat, 2003). To the extent that the use of adults as counterfactuals likely failed to control for changes in other highway-related laws and unmeasured historical factors, the GDL program effect estimates would be confounded by these factors.

In the interest of providing a complete critique of Vanlaar et al.'s (2009) study, two additional issues that have already been discussed in more detail for prior multi-state GDL studies should be briefly mentioned. All the GDL programs were combined into a single overall estimate of GDL program effect for each age group, regardless of the actual components and calibrations of the programs. Finally, multiple data points from the same states/provinces were included without attempting to adjust for this geodemographic clustering. If the effect estimates from the same state/province are indeed correlated as would be expected, failing to account for this clustering would bias the results towards finding reductions in driver fatalities associated with GDL programs and components.

Vanlaar et al.'s (2009) study was the most thorough effort up to that point in time to determine which GDL components and calibrations were associated with the largest changes in teen crash fatalities. However, the extremely large sizes of most of the effect estimates makes their validity dubious, because effect sizes this large are almost never seen in well-designed traffic safety research studies. It is also interesting that the only GDL core component found to be uniquely associated with the driver fatality ratios was that for passenger restrictions during the intermediate licensing stage for 16 year olds. The pattern of strange findings from the GDL component/calibration analyses strongly suggests problems with the estimation methods, multicollinearity (e.g., the overall IIHS licensing program quality ratings overlap with other coded elements), residual confounding (e.g., residual trends and effects of other highway-related law changes), model misspecification (e.g., several of the coded elements are actually subsets of other factors, such as exceptions to the passenger restrictions, which can only exist in states/provinces that have passenger restrictions), model misspecifications, small cell sizes (e.g., several of the coded categories have sample sizes less than five), or most likely some combination of these problems. Until the causes of the dubious effect sizes are resolved, these findings should be viewed cautiously.

d. McCartt, Teoh, Fields, Braitman, and Hellinga (2010) U.S. GDL Study

The most recent attempt to characterize the overall effects associated with GDL programs and to determine which GDL program components were associated with differences in teen fatal crash involvements was completed by McCartt, Teoh, Fields, Braitman, and Hellinga (2010). The authors used 1996–2007 (12 years) quarterly driver fatal crash involvements for 50 U.S. states (the District of Columbia was excluded) from FARS to create state-specific driver fatal crash involvement rates per 100,000 population. The design of the study was pooled cross-sectional time series and the analysis method was Poisson regression. Overall GDL program effect models were estimated separately for 15, 16, 17, 18, and 19 year olds, and GDL program component models were calculated separately for 15, 16, and 17 year olds. Aggregated involvement rates for 15–17 and 15–19 year olds were also analyzed. The state-specific contemporaneous crash rates of adults ages 30–59 were used as a covariate in the analyses in an attempt to remove confounding from all sources such as average differences in driver fatality rates among the states, trends, seasonality, changes in other highway-related laws, and other unmeasured historical factors. However, the adult driver fatal crash incidence covariate was not used in interactions with state or age group (when multiple ages were included in the analyses), so the models constrained whatever relationship existed between teen and adult driver fatal crash rates to be the same across all states, and in cases when involvement rates were aggregated across age groups, across all teen age groups as well.

For the analyses of overall GDL program effects McCartt et al. (2010) coded the driver licensing system in effect during each quarter in each state according to the IIHS licensing program quality rating system described earlier. Briefly, each quarter was classified as having a teen driver licensing system that was “Good,” “Fair,” “Marginal,” or “Poor” based on a weighted point scored ranging from 0–10 reflecting the types and calibrations of six of the seven GDL core components that were operating during that quarter (minimum unrestricted licensing age is the excluded component). Relative to licensing systems rated as “Poor,” those with a rating of “Good” were found to be associated with reliable decreases in fatal crash incidence of 44% for 15 year olds, 41% for 16 year olds, and 19% for 17 year olds, and non-reliable decreases of 4% for 18 year olds and 3% for 19 year olds. Programs rated as “Fair” were associated with reliable decreases of 25% for 15 year olds and 18% for 16 year olds, a non-reliable decrease of 3% for 17 year olds, and non-reliable increases of 3% and 2% for 18 and 19 year olds, respectively. Finally, licensing systems rated as “Marginal” were associated with a reliable increase in fatal crash incidence of 19% among 15 year olds, reliable decreases of 7% for 16 year olds and 4% for 18 year olds, and non-reliable decreases of 1% for 17 year olds and 2% for 19 year olds. When crashes were aggregated across 15–19 year olds, larger decreases in incidence were found as a function of higher program quality ratings with reductions of 15% for those rated as “Good,” 4% for those rated as “Fair,” and 2% for those rated as “Marginal.”

McCartt et al. (2010) also conducted analyses of which specific GDL core components and calibrations of those components were associated with changes in 15, 16, 17, and 15–17 year old (combined) fatal crash incidence. To do this each quarter was coded for the following GDL core components: (a) learner stage minimum entry age (continuous month of age); (b) required learner permit minimum holding period (continuous number of months); (c) number of required supervised driving hours (continuous number of hours); (d) intermediate licensing stage nighttime driving restriction (continuous number of hours restricted between 8:00 pm and 5:00 am); and (e) intermediate licensing stage passenger driving restriction (categorically coded as 0, 1, or 2+ teen passengers allowed). The GDL core components that were not coded separately were minimum intermediate licensing ages and minimum unrestricted licensing ages; instead these components were combined into minimum (unsupervised) driving age (continuous months of age). One implication of the coding strategy used for every variable except passenger restrictions is that all effects are constrained to be linear, so only monotonic increases or decreases (or no change) can be represented by the model parameters. The continuous variables were not centered, so the rate ratio estimates represent the change in incidence for a one-unit increase in the value of the variable (e.g., in months of age), starting from zero.

The results of McCartt et al.'s (2010) GDL component analyses indicated that requiring teens to be older to begin the learner stage was reliably associated with lower fatal crash incidence of 15 and 16 year olds, but no reliable change for 17 year olds. Specifically, a 6-month increase in the learner stage entry age was associated with 26% lower 15-year-old incidence and 11% lower 16-year old incidence. A 1-year increase in the learner stage entry age was associated with 46% lower 15-year-old incidence and 21% lower 16-year-old incidence.

McCartt et al. (2010) did not find required learner permit holding periods to be reliably associated with fatal crash rates of 15 or 16 year olds, but longer learner permit holding periods were reliably associated with higher incidence for 17 year olds. The point estimates suggested that 6-month learner permit holding periods were directionally consistent with 2% higher and 3% lower incidence for 15 and 16 year olds (respectively), and reliably 4% higher incidence for 17 year olds. The estimates for 12-month learner permit holding periods were 4% higher, 6% lower, and reliably 9% higher, respectively for each age group.

Required hours of supervised driving practice were not found by McCartt et al. (2010) to be reliably associated with changes in fatal crash incidence for any of the teen age groups. The point estimates for 40 hours of required supervised driving practice, which is the number of hours most commonly required by U.S. states, were directionally consistent with 4% lower incidence for 15 year olds, no change at all for 16 year olds, and 4% lower incidence for 17 year olds.

Requiring that teens be older to be able to drive unsupervised (whether as part of an intermediate licensing stage or not) was found by McCartt et al. (2010) to be reliably associated with lower fatal crash incidence for 15 and 16 year olds, but not 17 year olds. Specifically, an increase of 6 months in the age that teens are able to obtain a license to drive unsupervised was reliably associated with lower incidences of 37% for 15 year olds and 10%

for 16 year olds, and non-reliably 3% higher incidence for 17 year olds. The estimates for requiring them to be 1 year older to obtain such a license were 60% lower, 19% lower, and 6% higher (but not statistically reliable), respectively for these age groups. This pattern of findings is what would be expected given that older minimum unsupervised driving ages would certainly reduce driving by younger teens, but less so or not at all for older teens. However, the linear parameterization used for this variable and most others restricted the pattern of possible findings to be incremental increases or decreases, which almost guaranteed this pattern of findings. Further implications are discussed in more detail later.

McCartt et al. (2010) also found that, relative to allowing teens to transport two or more teen passengers, restrictions disallowing them from transporting any teen passengers (regardless of time length) were reliably associated with lower fatal crash incidences of 32% for 15 year olds, 23% for 16 year olds, and 18% for 17 year olds. Passenger restrictions allowing only one teen passenger were directionally consistent with 9% lower 15-year-old incidence and 5% lower 16-year-old incidence, though neither estimate was statistically reliable. However, passenger restrictions allowing only one teen passenger were reliably associated with 7% lower 17-year-old fatal crash incidence. The large effect for 15 year olds is striking because only five states with a passenger restriction allowed unsupervised driving by 15 year olds during the study time period.

Finally, McCartt et al. (2010) found that each additional hour of restricted driving from 8:00 pm to 5:00 am was reliably associated with lower fatal crash incidence for every teen age group. For example, nighttime driving restrictions starting at 10:00 pm were reliably associated with fatal crash incidences that were reliably 22% lower for 15 year olds, 25% lower for 16 year olds, and 9% lower for 17 year olds. The reductions were lower for restrictions starting later, such as 12:00 am, which was reliably associated with reductions of 16%, 18%, and 6% for these age groups, respectively.

When crash involvements were aggregated and analyzed across 15–17 year olds, the only GDL core components McCartt et al. (2010) found to be associated with reliable reductions were minimum learner stage entry ages, unsupervised licensing ages, nighttime driving restrictions, and passenger restrictions. Learner permit holding periods and supervised driving hours were not reliably associated with changes in 15–17-year-old aggregated fatal crash incidence.

The McCartt et al. (2010) multi-state study of GDL is the only one to provide estimates of the changes in teen fatal crash involvements associated with the full range of different calibrations for five of the seven GDL core components simultaneously adjusted for the effects associated with the others. Although it is the most recent effort, it is also likely the most confounded study of all those reviewed. The study has several serious methodological shortcomings, but the most important is inadequate adjustment for state- and age-specific differences in teen fatal crash incidence, trends, seasonality, autocorrelation, changes in other highway-related laws, and other unmeasured historical factors such as changes in roadway environments, traffic enforcement, and fuel prices. Instead it was argued that any attempt to remove these sources of confounding at the state level would reduce the GDL effect size estimates erroneously, because the enactment of the most rigorous GDL programs and program component calibrations is positively correlated with time (and therefore with factors that vary monotonically over time) and collinear with state. However, a longer pre-GDL time period of data would have allowed such adjustments to be made without the estimates being completely confounded with states' GDL efforts. The single adjustment made for all these sources of confounding (contemporaneous 30–59 year old fatal crash incidence rates) was constrained to have the same relation across all states and age groups despite the evidence presented in the study showing that teen fatal crash incidence was trending downward during the entire study period, and that these trends appear different across teen age groups. Additional evidence not presented (see Figure 4) – and perhaps the need to examine such evidence was not realized – demonstrates that teen driver fatal crash involvements rates are very different across states, the rates were trending downward more strongly in some states than in others, and some states' rates were actually increasing. Because only a single adjustment was made for all these factors, the effect estimates are probably confounded by the effects of state- and age-specific baseline differences in teen fatal crash incidence, trends, seasonality, changes in other highway-related laws, and other unmeasured historical factors.

Although the IIHS ratings of GDL program quality are widely cited, they involve a somewhat arbitrary amalgamation of subjective judgments. The conclusions about the effects associated with programs of varying overall quality are consequently difficult to interpret. According to this rating scheme, a teen driver licensing system without a learner permit stage could theoretically be rated as a "Good" GDL program, even though it would not meet the simple definition of being a three-stage GDL program. The use of this coding scheme makes it difficult to interpret exactly what comparisons to the "Poor" quality referent group represent because this category includes a wide range of teen driver licensing systems rather than just programs with no special requirements for teens.

McCartt et al. (2010) parameterized most of the included GDL core components as continuous variables, which makes the assumption that the relation between the component and crash incidence is linear across all real or theoretical calibrations of the component. Linear parameterization also only allows the effect estimates to monotonically increase or decrease across values, which constrains any estimated effects to conform to a monotonic pattern. In any situation where the relation between the GDL component and crashes is non-linear or non-monotonic this parameterization would incorrectly represent the actual relation between the component and teen fatal crash incidence. No theoretical argument or empirical evidence is presented that the relations between GDL components and crash incidence are reasonably approximated by linear parameterization, and there are reasons to believe that this approach may be unwise in some cases. For example, nighttime driving restrictions starting earlier in time target a larger proportion of total teen driving because more of them drive during the early hours of the evening than later at night (Rice et al., 2003). Because the density of teen driving exposure decreases from the early evening to the early morning hours, and any potential crash reductions are constrained by the level of driving exposure, it follows that restricting driving in earlier hours of the night has a larger potential effect than does restricting driving during later hours. The linear parameterization makes it impossible to conclude that some restriction start times are not at all associated with lower crash incidence, while others are, because the only conclusions possible from linear parameterization are that more hours, regardless of start time, are associated with incremental increases or decreases in crashes (or that there is no association at all).

The degree to which non-linear or non-monotonic relations between the GDL components and crash involvements are hidden in the McCartt et al. (2010) study due to this linear parameterization of effects is unknown because rate ratios for actual categorizations of these variables were not provided. However, this potential problem exists for every GDL component in the study except passenger restrictions. There are also potentially flawed policy implications that could result from this coding strategy. For example, coding the age-related components in a linear manner, paired with inadequate adjustment for preexisting downward trends, would lead to findings that support policies of raising minimum licensing ages. Because the intermediate licensing age and unrestricted licensing age GDL components were combined into a single variable it was not possible to disentangle their effects.

In the spirit of being thorough, there are a few other problems with the McCartt et al. (2010) study that should be briefly mentioned. First, the models were not adjusted for the likely dependency (autocorrelation) among quarters. Not taking geodemographic clustering into account may have resulted in standard errors that are smaller than is warranted, which would bias the results towards finding statistically reliable effects. This is of particular concern because a strict hypothesis testing approach was used and confidence intervals were not provided that could be used to judge the relative precision of the estimates. The study also included 15 year olds, who were only licensed to drive unsupervised in nine of the 50 included states during the study period. In reviewing 15-year-old driver quarterly fatal crash involvement counts for the current study it was determined that 55% of the 15-year-old quarters in their study had zero crash involvements and 25% had only a single involvement. This low number of crash events may have led to over-dispersion problems with the Poisson models and unstable parameter estimates. Including an age group to whom most GDL elements do not apply in over 80% of the states adds noise to age-aggregated comparisons and little to the overall understanding of GDL programs. Related to this issue are the seemingly nonsensical findings suggesting that 15-year-old fatal crash involvements are influenced by nighttime and passenger driving restrictions and other GDL components that do not apply to them. This may be ad hoc evidence of residual state-specific confounding or trends rather than something that actually results from the particular GDL elements, which would highlight the most important methodological shortcoming of this study—inadequate adjustment for state- and age-specific sources of confounding.

e. Summary of Problems with Prior Multi-State GDL Studies

All of the multi-state studies of overall GDL program effects and GDL program components completed to date have shortcomings or methodological flaws that limit their usefulness. The criticisms of these studies just presented broadly fall into four categories: (a) poor study design and the resulting inability to address important questions (e.g., assuming GDL effects are the same across all teen age groups); (b) failure to control for important confounding factors (e.g., state-specific differences, trends, and the effects of other highway-related law changes); (c) findings that appear to be artifacts of the modeling approach used (e.g., linear parameterization of GDL components and dichotomous categorization of teen driver licensing systems); and (d) accepting and reporting findings that are simply inconsistent with how GDL works, should work, or might work (e.g., extreme effect sizes for minor program components). To summarize the lengthy critical reviews just presented, the 10 most important limitations identified in one or more prior multi-state GDL studies are listed below:

1. Combining different ages of teens into a single age group (e.g., 15–17 year olds), which assumes that GDL programs are associated with a homogenous effect for teens of all ages;

2. Combining crash rates across states without adjusting them for baseline state-specific differences, which results in confounded effect estimates;

3. Calculating estimates for program components or calibrations that have too few data points or data points from too few states such that it results in estimates that are likely unstable or confounded by state;

4. Failing to adjust for within-state changes and between-state differences in other highway-related laws (e.g., seat belt use, speed limits, and alcohol-related laws), which results in confounded effect estimates;

5. Failing to adequately adjust for state- and age-specific trends in teen fatal crash incidence, including having too few pre-GDL data points to estimate trends accurately, or using a single national trend adjustment, which results in GDL effect estimates that are still confounded;

6. Combining all GDL-like teen driver licensing systems or all three-stage GDL programs to obtain an overall estimate of GDL program effect without regard for the specific components included or the meaningfulness of the calibrations (e.g., programs with short learner permit holding periods or only a trivial restriction during the intermediate licensing stage), which results in effect estimates that are difficult to interpret;

7. Assuming that standardizing changes in teen crash incidence to changes observed in adult crash incidence (i.e., the adults-as-counterfactual approach) is adequate to remove the effects associated with trends, changes in other highway-related laws, and other unmeasured historical confounders when the effects of these factors are likely different for teens and adults, which results in effect estimates that are still confounded;

8. Excluding data points in the middle of time series which makes it difficult to model continuous trend and seasonality and exacerbates any bias associated with residual downward trends by comparing time points that are temporally more distant;

9. Failing to account for autocorrelation when using repeated measurements of age groups within states (geodemographic clustering), which results in standard errors that are too small and a bias towards finding statistically reliable effects; and

10. Using crude GDL component categories that ignore potentially important variations in component calibrations (e.g., categorizing nighttime driving restrictions as yes/no without regard to start times) or parameterizing the components in a manner than constrains the findings to fit a particular pattern (e.g., using linear parameterization).

CHAPTER 2

II. RATIONALE AND SPECIFIC AIMS

A. Study Rationale

GDL programs may be the most promising intervention that driver licensing agencies have for mitigating the high crash rates of teen drivers, because they address all three primary risk factors for high 16–17-year-old crash rates (i.e., inexperience, age-related surrogate factors, and high-risk driving circumstances). Many single-state studies of GDL programs have been completed and most indicate that such programs are associated with crash reductions among young teens. However, the GDL components that define each program and the calibrations of those components differ across states and the studies vary dramatically in methodologies, data sources, analytic strategies, and the obtained effect sizes. Several multi-state studies of GDL programs have been completed to obtain more global estimates of GDL effectiveness and to avoid the problems associated with trying to draw conclusions from heterogeneous single-state studies. However, each of the multi-state GDL studies completed so far has one or more of the problems outlined above, which hampers making inferences about net GDL program effectiveness for all teens or makes the validity of the obtained results questionable.

Furthermore, none of the prior multi-state GDL studies satisfactorily answered the most important question about specialized teen driver licensing systems: Is there a net overall reduction in "teen driver" crashes associated with implementing these programs? This is particularly relevant given that there is some evidence that GDL programs may be associated with higher crash rates among some older teens (e.g., Males, 2007; Vanlaar, Mayhew, Marcoux, Wets, Brijs, & Shope, 2009) and there is a logical reason to believe that such effects might be real (McKnight et al., 2002; Williams & Mayhew, 2008). Specifically, younger teens may delay licensure until they are no longer subject to the GDL program requirements, which would increase the proportion of beginning drivers among 18 and 19 year olds. For example, Figure 6 shows the percentages of 16, 17, 18, and 19 year olds licensed to drive unsupervised in California each year from 1986–2007.

While the percentages of 16 and 17 year olds licensed to drive unsupervised after the California GDL program was implemented are lower than beforehand (reductions of 7 and 4 percentage points, respectively), the percentages of licensed 18 and 19 year olds increased (2 and 4 percentage points, respectively). In fact, implementation of the GDL program appears to be associated with changes in long-term trends towards reduced licensure among 18 and 19 year olds in California. The lower post-GDL licensing rates for 16 and 17 year olds, combined with the reversal of pre-GDL declining trends in licensure among older teens, indicates that more California teens are being licensed at ages 18 and 19 than before GDL, probably because they are not subject to the GDL requirements if they are licensed at age 18 or older. California teens licensed at age 18 or older would not receive any potential benefits of mandatory driver education and training because they are also not required of persons age

18 or older. If similar patterns exist in other states, it provides a logical mechanism to explain why GDL programs might be associated with higher crash rates among older teens, given that higher proportions of older teens would be novice drivers after GDL than beforehand. Hence this study also included 18 and 19 year olds so that any changes in their crash rates associated with GDL programs could be estimated, along with the overall net association for all "teen drivers" associated with GDL programs.

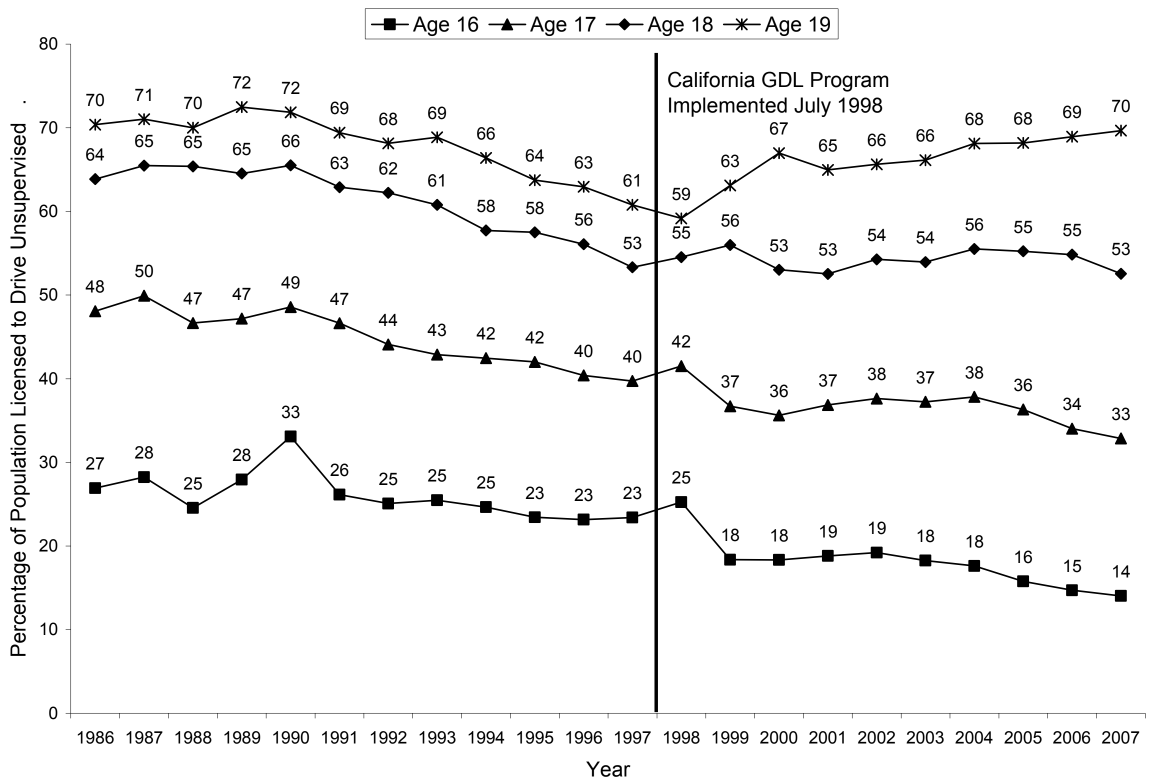


Figure 6. Annual percentages of 16, 17, 18, and 19 year olds licensed to drive unsupervised in California, 1986–2007.

With the possible exceptions of nighttime and passenger driving restrictions, not much is known about which core components of GDL programs are specifically associated with lower teen crash involvements. Furthermore, it is not known which calibrations of those

GDL components are associated with the largest reductions in teen crash involvements. Comparisons among the spectrum of calibrations for each GDL core component could be informative for deciding which components to include and for optimally calibrating those components in GDL programs. None of the multi-state GDL studies completed so far have adequately accomplished this feat. Not only does each study have shortcomings or methodological flaws that limit drawing conclusions from the findings regarding the overall net effects associated with GDL programs, they also have problems that specifically hamper drawing conclusions about the effects associated with, and best calibrations for, each of the individual GDL components. None of the prior multi-state GDL studies produced effect estimates for each of the seven GDL core components that were simultaneously adjusted for the effects associated with all other GDL components and important age- and state-specific confounders. When effects associated with the individual GDL components were estimated in these studies, they were either based on unnecessarily broad categorizations of the components that ignored potentially important variation in the calibrations, or were parameterized in a manner that constrained the findings to fit a linear pattern. In all cases, at least one of the GDL core components was excluded altogether.

At most, the prior multi-state GDL studies suggest that these programs reduce fatalities among some teen age groups and that programs of seemingly better quality or those that include more core components are associated with even larger fatality reductions. A better method for conducting a multi-state GDL study would be to perform an analysis of crash rates for all teen drivers in which the specific calibrations for each of the seven GDL core components is coded and a model is formulated that adjusts for state- and age-specific trends, seasonality, changes in other highway-related laws, and other unmeasured historical confounders, similar to the approach of Villaveces et al. (2003) in their analysis of U.S. alcohol-related laws. The purpose of the present study is to conduct the most methodologically rigorous multi-state study of GDL programs and GDL program components to date that avoids to the greatest extent possible the problems identified for prior studies. The goals are to obtain age-specific estimates of changes in driver fatal crash involvement rates associated with implementing different types of teen driver licensing systems in the U.S. (including GDL programs), determine the net change in driver fatal crash involvements for 16–19-year-olds (combined) associated with implementing these teen driver licensing systems, and identify which GDL core components and calibrations are associated with the largest reductions in driver fatal crash involvements so that this information can be used to optimally calibrate these individual GDL components.

B. Specific Aims

The specific aims of this study are to use pooled cross-sectional time series analyses of quarterly driver fatal crash involvement rates per capita for all U.S. states from 1986–2007 in Poisson regressions with generalized estimating equations, adjusted for age- and state-specific trends, seasonality, changes in other highway-related laws, and other unmeasured historical confounders, and that avoids to the greatest extent possible the shortcomings and methodological flaws in prior multi-state GDL studies, to do the following:

A. National Study of Teen Driver Licensing Systems

1) Determine whether the following types of teen driver licensing systems are associated with changes in driver fatal crash involvement rates for 16, 17, 18, and 19 year olds separately:

   (a) Two-stage systems with only a short learner permit holding period (< 3 months);

   (b) Two-stage systems with only a longer learner permit holding period (≥ 3 months);

   (c) Two-stage systems with only an intermediate (unsupervised, but initially restricted) license stage (with 1–2 driving restrictions);

   (d) Three-stage systems (GDL) with only one licensing restriction during the intermediate licensing stage; and

   (e) Three-stage systems (GDL) with two licensing restrictions during the intermediate licensing stage;

2) Determine the net overall changes in teen driver (16–19 year olds combined) fatal crash involvements associated with implementing these teen driver licensing systems;

B. National Study of GDL Program Core Components

3) Determine whether the following seven GDL program core components are associated with changes in driver fatal crash involvement rates for 16, 17, 18, and 19 year olds (separately), and how any effects vary as a function of the specific component calibrations:

   (a) Learner stage minimum entry age;

   (b) Learner permit minimum holding time period;

   (c) Supervised driving hours required;

   (d) Intermediate license stage minimum entry age;

   (e) Nighttime driving restriction (intermediate licensing stage);

   (f) Passenger driving restriction (intermediate licensing stage); and

   (g) Unrestricted licensing stage minimum entry age;

4) Describe which GDL program core components should be included in programs and how the individual components might be optimally calibrated by determining which

component calibrations are associated with the largest net overall reductions in teen driver fatal crash involvements (16–19 year olds combined);

C. Methodological Sensitivity Analyses

5) Compare and describe how the results of the overall teen driver licensing system and GDL program component analyses vary as a function of whether, and which, adult age group driver fatal crash involvement rates are used as contemporaneous covariates to remove state-specific historical variability from unmeasured factors.

The following details the pages of the manuscript where the statistical results and discussion addressing each specific aim can be found:

Specific aim	Results	Discussion
1. Teen Licensing Systems × Individual Age Group	93–113 (specific) 113–116 (summary)	176–182
2. Teen Licensing Systems 16–19 (combined)	116–122	
3. GDL Components × Individual Age Group	123–150 (specific) 150–165 (summary)	182–193
4. GDL Components 16–19 (combined)	169–174	
5. Methodological/ Sensitivity (variation in adult crash covariates used)	93–113 (specific teen licensing) 113 (summary teen licensing) 123–150 (specific GDL components) 150–151 (summary GDL components)	194

CHAPTER 3

III. METHODS

A. Data Sources

Driver fatal crash involvements for cars, pickup trucks, vans/minivans, and sport utility vehicles were obtained from the Fatality Analysis Reporting System (FARS) for 1986–2007 (22 years) for all 50 U.S. states and the District of Columbia (NHTSA, 2010). While it might have been preferable to use crash data for a wider range of severity levels, no single census of non-fatal crashes in the U.S. exists and others who have tried to obtain non-fatal crash data individually for large numbers of U.S. states have been unsuccessful (e.g., Chen et al., 2006). FARS is a yearly census of U.S. motor vehicle crashes on public roadways that within 30 days of the crash result in a fatality to a vehicle occupant or non-motorist. The data are provided to NHTSA by trained coders in each U.S. state and checked for consistency by NHTSA staff. Crash involvements for drivers younger than age 16 or with a missing age were excluded. The crash involvements were aggregated by state, age group (i.e., age 16, 17, 18, 19, 20–24, 25–39, 40–59, and 60+), and quarter (i.e., January–March, April–June, July–September, and October–December for each year).

Hence the unit of analysis was state age-group quarters. The original intent was to also include 15 year olds in the analyses (*n* = 3,955 driver fatal crash involvements from 1986–2007). However, this plan was abandoned after discovering that only 10 states allowed unsupervised driving by 15 year olds during any quarter of the 22-year study period, and the fact that 53% (*n* = 2,370) of the quarters for 15 year olds had zero driver fatal crash involvements, which resulted in convergence problems for the statistical models. For each included age group, in each state, there were 88 quarters (22 years × 4 quarters), which amounts to 704 quarters for each state (88 quarters × 8 age groups) and a grand total of 35,904 state age-group quarters (704 age-group quarters × 51 states). Each teen age group had 4,488 quarters (22 years × 4 quarters × 51 states) for a total sample size of 17,952 quarters (4 teen age groups × 4,488) used in the analyses.

Single-year-of-age population estimates for each state were obtained from the U.S. Census Bureau for 1985–2008. Quarterly values were interpolated between the annual July estimates using cubic spline curves for each age group in each state. Cubic spline curves are third-degree polynomial functions constrained to pass through the given data points, as implemented in the SAS EXPAND procedure. The purpose of producing the quarterly population interpolations was to allow the creation of quarterly driver fatal crash involvement rates per 100,000 population for each age group. Population-based rates were used rather than driver-based rates because: (a) no reliable national source for licensed driver counts exists given the problems noted by others with FHWA license data, particularly for young drivers (Ferguson, Teoh, & McCartt, 2007; Foss, 2007; IIHS, 2006); and (b) some of the effects associated with GDL programs likely result from delayed or reduced unsupervised licensure, which would not be captured in the rate ratios if the crash involvement rates were calculated on a per-licensed-driver basis (McKnight, Peck, & Foss, 2002).

B. Coding of Teen Driver Licensing Systems and Other Highway-Related Laws

1. Coding of GDL Program Core Components

Each quarter was coded for the seven different GDL core components shown in Table 1. The categories (calibrations) coded for each GDL core component were initially even more specific, but these more-specific categories were collapsed into those shown in the table to ensure that each final category contained at least five different states to reduce the likelihood that the GDL component effects would be confounded by state-specific results. The numbers of quarters per age group and unique states contributing at least one quarter to each category are also shown in the table.

The coding of the GDL core components from 1994–2007 was based largely on historical documentation of changes in state teen driver licensing systems maintained by the Insurance Institute for Highway Safety (2009c) and existing coding provided by the American Automobile Association Foundation for Traffic Safety (AAAFTS) that was used in their *Nationwide Review of Graduated Driver Licensing* (AAAFTS, 2007). The coding of teen driver licensing requirements before 1994 was largely based a series of reports published approximately every 2 years from 1967–1996 called *Driver License*

Table 1. GDL Program Core Component Categories, Number of Quarters for each Age Group in each Category, and Number of Unique States Contributing to each Category

GDL core component categories	Quarters per age group		Unique states	
	n	%	*n*	%
Learner permit age (minimum)				
< 15 years	747	16.6	9	17.6
15 years–15, 5 months	2,050	45.7	28	54.9
15, 6 months–15, 11 months	854	19.0	14	27.4
16 years	837	18.6	14	27.4
Learner permit holding period				
None	2,330	51.9	44	86.3
< 3 months	466	10.4	10	19.6
3–4 months	442	9.8	13	25.4
5–6 months	1,069	23.8	42	82.3
9–12 months	181	4.0	6	11.8
Supervised driving hours (total)				
None required	3,472	77.4	51	100.0
≤ 20 hours	137	3.0	6	11.8
25–35 hours	192	4.3	6	11.8
40 hours	186	4.1	11	21.6
50–60 hours	501	11.2	21	41.2
Intermediate stage license age				
No intermediate license stage	2,658	59.2	42	82.3
< 16 years	389	8.7	8	15.7
16 years–16, 5 months	1,204	26.8	36	70.6
16, 6 months–17 years	237	5.3	8	15.7
Nighttime driving restriction				
No nighttime driving restriction	2,952	65.8	45	88.2
≤ 10:00 pm	239	5.3	6	11.8
11:00 pm	212	4.7	10	19.6
12:00 am	856	19.1	24	47.1
1:00 am	229	5.1	8	15.7
Passenger driving restriction				
No passenger restriction	3,681	82.0	51	100.0
0 passengers, < 6 months	91	2.0	5	9.8
0 passengers, ≥ 6 months	289	6.4	13	25.5
1 passenger, ≥ 6 months	279	6.2	19	37.2
2–3 passengers, ≥ 6 months	148	3.3	7	13.7
Unrestricted license age				
15 years–15, 11 months	252	5.6	5	9.8
16 years–16, 5 months	2,599	57.9	43	84.3
16, 6 months–16, 11 months	304	6.8	13	25.5
17 years–17, 5 months	842	18.8	22	43.1
17, 6 months–18 years	491	10.9	15	29.4

Note. Each age group had 4,488 quarters across all states and years. Quarter percentages do not add to 100% due to rounding. State percentages indicate the percentage of the 51 states contributing at least one quarter to each category across all years; the counts add to greater than 51 because some states changed categories over time. Nighttime and passenger restrictions were only included if they specifically applied to 16- or 17-year-old drivers. Because some restrictions have multiple stages (e.g., 1st 6-months vs. 2nd 6 months) only the first-occurring restriction phase was coded. Further, because the application of restrictions is sometimes different for 16 and 17 year olds, the quarters were coded based on restrictions as they applied to 16 year olds. No states required supervised driving hours that fell in the ranges between the categories shown.

Administration Requirements and Fees (FHWA, 1984, 1986, 1988, 1990, 1992, 1994, 1996) and a report by the American Association of Motor Vehicle Administrators titled

Comparative Data: State and Provincial Licensing Systems (1999). The information in these reports was also compared to that from the IIHS and AAAFTS sources where possible to insure consistency across these sources. Discrepancies in the information across these sources were resolved through primary research of state vehicle codes, chaptered bills, statutes, and regulations, along with searches of other published reports on teen driver licensing systems, historical news articles, and contacts with legislative and licensing officials in various states.

The GDL core components for each state were coded based on determining the pathway to teen licensure that resulted in receiving a full, unrestricted license as quickly as possible. Often this involved requirements to complete driver education and driver training courses to avoid additional required hours of supervised driving practice, qualify for a license to drive unsupervised sooner, or avoid license restrictions. The exception to this rule was in regard to hardship licenses (e.g., a license allowing young teens to drive to and from school only), which were not considered to be a viable option for most teens and were therefore not considered to be part of the normal pathway for teen licensure. While assuming that teens go through each state's licensing system as early and quickly as possible is clearly erroneous (e.g., only 13% of California 16 year olds were licensed to drive unsupervised in 2007), it was necessary to use a consistent strategy for coding licensing systems and components across states so the coding procedure could be replicated by others. Nighttime and passenger driving restrictions were only coded as being in effect in a quarter if they applied specifically to 16- or 17-year-old drivers during an unsupervised licensing stage. These restrictions sometimes differed in application to 16 and 17 year olds within a state (e.g., in some cases the restriction applied to 16 year olds but not 17 year olds). Furthermore, the restrictions sometimes had multiple stages (e.g., no passengers for the 1^{st} 6 months of unsupervised licensure, and no more than one passenger for the 2^{nd} 6 months). To make the coding of restrictions consistent across both age groups in such cases, the first-occurring phases of multi-phase restrictions as they applied to 16 year olds were coded for the analyses. A GDL core component was considered to be in effect during an entire quarter if it was implemented for at least 2 of the 3 months in the quarter (± up to 5 days).

2. Coding of Teen Driver Licensing Systems

In addition to quarters being coded for each of the seven GDL program core components, they were also coded at a macro level to reflect the overall teen driver licensing system that was in effect in the state during each quarter. The purpose of categorizing the quarters according to the overall teen driver licensing system was to enable higher-level comparisons among: (a) 1-stage teen driver licensing systems under which young teens are allowed to apply for and obtain an unrestricted license without a learner permit holding period or intermediate licensing stage; (b) 2-stage systems with only a learner permit holding period (separately coding those lasting <3 months and those lasting ≥3 months); (c) 2-stage systems with only an intermediate licensing stage (i.e., unsupervised, but initially subject to nighttime and/or passenger restrictions, but no required learner permit holding period); (d) 3-stage GDL programs with only one driving restriction during the intermediate licensing stage (either nighttime or passenger); and (e) 3-stage GDL programs with both nighttime and passenger driving restrictions during the intermediate licensing stage.

Overall teen driver licensing systems were classified using two different coding strategies (i.e., “stronger” vs. “weaker”) meant to crudely differentiate between those that had learner permit holding periods and driving restriction components calibrated in a meaningful manner versus those in which the calibrations were likely inconsequential. For example, the length of mandatory learner permit holding periods varied across states from 7 days to 12 months. While the former is technically a learner permit holding period, it is so short that it is likely ineffectual. Passenger restriction calibrations ranged from zero passengers allowed to “no more passengers than there are seat belts” and nighttime driving restrictions ranged from “sunset to sunrise” to 1:00 am–5:00 am. Short learner permit holding periods, passenger restrictions allowing more than one teen passenger, and nighttime driving restrictions starting after midnight target only a limited scope of teen driving and therefore seem likely to have a negligible impact on crashes (Chen et al., 2000). The purpose of classifying the teen licensing systems using two coding strategies was to be able to compare the results when stringency with respect to these three components is taken into account or ignored. The overall teen licensing system parameter estimates are considered to be meaningfully different across models if they differed by 10% or more from the stronger-coding model parameters.

Under the “stronger” coding strategy, three-stage teen licensing systems were categorized as GDL programs only if these three components were non-trivially calibrated, as defined by the following three criteria: (a) the learner permit holding period had to last at least 3 months; (b) any nighttime driving restriction had to start before 1:00 am; and (b) any passenger restriction had to allow no more than one passenger younger than age 20 in the vehicle. Under the second “weaker” coding strategy, three-stage teen licensing systems were categorized as GDL programs regardless of how trivial the calibrations of the learner permit holding periods and nighttime/passenger driving restrictions might be. The differentiation between weaker and stronger GDL programs is not intended to suggest that 3 month or longer learner permits, nighttime driving restrictions starting before 1:00 am, and passenger restrictions allowing only one passenger are strong, good, adequate, or desirable; only that they are likely not totally inconsequential. Table 2 shows the numbers of quarters per age group and unique states contributing at least one quarter to each coded category of overall teen driver licensing system under the two coding strategies.

Table 2. Teen Driver Licensing System Categories, Number of Quarters for each Age Group in each Category, and Number of Unique States Contributing to each Category

Teen driver licensing system categories	Quarters per age group		Unique states	
	n	%	*n*	%
Stronger coding of components[a]				
1-stage (no learner permit or intermediate licensing stage)	1,989	44.3	39	76.5
2-stage (learner permit holding period only < 3 months)	359	8.0	8	15.7
2-stage (learner permit holding period only ≥ 3 months)	654	14.6	20	39.2
2-stage (intermediate licensing stage only with 1–2 restrictions)	448	10.0	10	19.6
3-stage with one restriction during intermediate licensing stage (GDL)	578	12.9	24	47.0
3-stage with two restrictions during intermediate licensing stage (GDL)	460	10.2	26	51.0
Weaker coding of components[b]				
1-stage (no learner permit or intermediate licensing stage)	1,989	44.3	39	76.5
2-stage (learner permit holding period only < 3 months)	359	8.0	8	15.7
2-stage (learner permit holding period only ≥ 3 months)	522	11.6	15	29.4
2-stage (intermediate licensing stage only with 1–2 restrictions)	341	7.6	8	15.7
3-stage with one restriction during intermediate licensing stage (GDL)	592	13.2	21	41.2
3-stage with two restrictions during intermediate licensing stage (GDL)	685	15.3	35	68.6

Note. Each age group had 4,488 quarters across all states and years. State percentages indicate the percentage of the 51 states contributing at least one quarter to each category across all years; the counts add to greater than 51 because some states changed categories over time. One-stage systems do not have a learner permit holding period or intermediate licensing stage. Two-stage learner permit-only systems do not have an intermediate licensing stage. Two-stage intermediate licensing stage only systems do not have a learner permit holding period. Three-stage systems with one restriction could have either a nighttime or passenger driving restriction during the intermediate licensing stage. Three-stage systems with two restrictions have both nighttime and passenger driving restrictions. GDL = Graduated driver licensing. [a]Only learner permit holding periods lasting 3 months or longer, nighttime driving restrictions starting before 1:00 am, and passenger restrictions allowing no more than 1 passenger < age 20 were deemed valid for being classified as a three-stage system. [b]Any learner permit holding period length of time, any nighttime driving restriction, and any passenger restriction were deemed valid for being classified as a three-stage system.

For purposes of classifying quarters into overall teen driver licensing systems, an "intermediate licensing stage" was defined as a licensing stage allowing 16 year olds (or 16–

17 year olds) to drive unsupervised, but initially subject to one or both of the following restrictions: (a) a nighttime driving restriction or (b) a passenger driving restriction. Under the stronger coding strategy at least one of the driving restrictions had to be non-trivial as defined above for the quarters to be classified as having intermediate licensing stages. Under the weaker coding strategy having any nighttime or passenger driving restriction that applied specifically to unsupervised 16 or 17 year olds was sufficient for quarters to be classified as having an intermediate licensing stage. However, under both strategies the "passenger restrictions" were disregarded if they only limited the number of passengers to the number of seats or seat belts available in the vehicle or if they only applied during times when the teens were already forbidden from driving due to nighttime driving restrictions. Also excluded from this definition of an intermediate licensing stage are systems with nighttime or passenger restrictions that applied only to learner permit holding periods, and other types of specifications such as requirements to wear seat belts or systems with only expedited post-licensing control programs (e.g., early provisional licensing programs).

One-stage licensing systems have neither a learner permit holding period nor an intermediate licensing stage. Two-stage licensing systems have either a learner permit holding period or an intermediate (unsupervised, but initially restricted) licensing stage. Two-stage learner-permit-holding-period-only systems were further divided into those with holding periods lasting less than 3 months and those with holding periods lasting 3 months or longer. The purpose of doing this was to be able to separately estimate the effects associated with short learner permit holding periods as well as those of a more substantial length. Under the stronger coding strategy the learner permit holding periods had to be non-trivial as defined above for the quarters to be classified as having GDL programs. Under the weaker coding strategy learner permit holding periods of any length were deemed to be “a learner stage” for purposes of classifying quarters as having GDL programs. Two-stage intermediate-stage-only systems have only an intermediate (unsupervised, but initially restricted) licensing stage with a nighttime or passenger driving restriction, as defined above under the weaker and stronger coding strategy criteria. Three-stage (GDL) programs have both learner permit holding periods and intermediate licensing stages that meet the criteria under the weaker and stronger coding strategies. These systems were further divided into those having only one driving restriction during the intermediate licensing stage (nighttime or passenger) and those having both types of driving restrictions during the intermediate licensing stage. This was done to make it possible to separately estimate the effects associated with GDL programs with one versus two intermediate licensing stage driving restrictions.

3. Coding of Other Highway-Related Laws

The U.S. states differed with regard to and also changed or implemented several other highway-related laws (e.g., *per se* blood alcohol concentration [BAC] limits, maximum speed limits, and seat belt laws) during the study time period that could also affect driver fatal crash involvement rates over time. The influence of these law changes could confound the effect estimates for the GDL program core components and overall teen driver licensing systems if they are not taken into account in the analyses through statistical adjustments. Therefore, the quarters were also coded for the six other highway-related laws shown in Table 3. From 1986–2007 8% of U.S. states (n = 4) enacted changes to only three of these other highway-related laws, 27% (*n* = 14) changed only four, 43% (*n* = 22) changed only five, and 22% (*n* = 11) made changes to all six. In addition, many states enacted multiple changes to the same law (e.g., first enacting a secondary-enforcement seat belt law [when law enforcement cannot stop the vehicle solely for a seat belt use violation] and then changing it to a primary-enforcement seat belt law [when law enforcement can stop the vehicle solely for a seat belt use violation]).

Table 3. Other Highway-Related Law Categories, Number of Quarters for each Age Group in each Category, and Number of Unique States Contributing to each Category

Other highway-related law categories	Quarters per age group		Unique states	
	n	%	*n*	%
Maximum speed limit (MPH)[a]				
55	726	16.2	51	100.0
65	2,411	53.7	49	96.1
70	792	17.6	23	45.1
≥75	559	12.5	13	25.5
Mandatory seat belt use[a]				
None	624	13.9	39	76.5
Secondary enforcement	2,664	59.4	42	82.3
Primary enforcement	1,200	26.7	27	52.9
Minimum legal drinking age of 21[b]				
No	210	4.7	29	56.9
Yes	4,278	95.3	51	100.0
Zero-tolerance for all ages < 21[a]				
No	1,930	43.0	51	100.0
Yes	2,558	57.0	51	100.0
BAC *per se* alcohol limit[c]				
≥ 0.10 or no limit	243	5.4	8	15.7
0.10	2,555	56.9	48	94.1
0.08	1,690	37.7	51	100.0
Administrative *per se* for all ages[c]				
No	1,558	34.7	33	64.7
Yes	2,930	65.3	41	80.4

Note. MPH = miles per hour. Secondary enforcement = law enforcement cannot stop the vehicle solely for a belt use violation. Primary enforcement = law enforcement can stop the vehicle solely for a belt use violation. BAC = blood alcohol concentration. Administrative *per se* = administrative license suspension/revocation for BAC ≥ the *per se* limit, regardless of age or prior offense history. Each age group had 4,488 quarters across all states and years. State percentages indicate the percentage of the 51 states contributing at least one quarter to each category across all years; the counts add to greater than 51 because some states changed categories over time.
[a]Based on coding provided by Thomas Dee (Dee, 2001; Dee, Grabowski, & Morrisey, 2005), Donald Freeman (2007), and other sources.
[b]The coding for minimum legal drinking age reflects grandfathering, rather than purely statutory age, based on the work of Lovenheim and Slemrod (2010). [c]Based on primary coding of state statutes provided by Alexander Wagenaar (Wagenaar & Maldonado-Molina, 2007; Wagenaar, Maldonado-Molina, Erickson et al., 2007; Wagenaar, Maldonado-Molina, Ma et al., 2007).

The coding of the other highway-related laws was based on reconciling existing coding obtained from several different sources, updating the coding where necessary to extend the time period to 2007, and adding coding for Alaska, Hawaii, and the District of Columbia. Coding for state maximum speed limits, seat belt laws, zero tolerance alcohol laws, BAC *per se* alcohol limits, and administrative license suspension/revocation for 1982–2006 was obtained from Thomas Dee (Dee, 2001; Dee, Grabowski, & Morrisey, 2005). This coding was compared with another independent source of coding for these laws plus that for statutory minimum legal drinking ages from 1980–2004 obtained from Donald Freeman (Freeman, 2007). Coding for minimum legal drinking ages from 1967–2004, including adjustments for grandfathering during the implementation of these laws, was obtained from Michael Lovenheim (Lovenheim & Slemrod, 2010). Independent coding based on primary research of state statutes from 1976–2002 that included coding for BAC *per se* limits, administrative *per se* license suspension/revocation, and other alcohol-related laws was obtained from Alexander Wagenaar (Wagenaar & Maldonado-Molina, 2007; Wagenaar, Maldonado-Molina, Erickson et al., 2007; Wagenaar, Maldonado-Molina, Ma et al., 2007).

The codes from the secondary sources identified above were compared and further checked against a number of other available compilations of highway-related laws including Bernat, Dunsmuir, and Wagenaar (2004), Dang (2008), Hedlund, Ulmer, and Preusser (2001), Wagenaar, O'Malley, and LaFond (2001), Zador, Lund, Fields, and Weinberg (1989), the web site for the National Conference of State Legislatures (2004), and the web site for IIHS (2009d). Where preexisting coding was not available (e.g., for Alaska, Hawaii, and Washington D.C., and for all states in 2007) or there were differences among the various sources, the quarters were coded based on primary research of state vehicle codes, chaptered bills, statutes, and regulations, along with searches of other published reports on highway-related laws, historical news articles, and contacts with legislative and licensing officials.

Reconciled coding from Dee and Freeman was used for speed limit, seat belt, and zero-tolerance laws in the analyses. The minimum legal drinking age coding from Lovenheim and Slemrod (2010) was chosen over the other sources because it took into consideration the grandfathering of these laws when they were implemented and would therefore be more accurate than simply using statutory minimum legal drinking ages. The coding provided by Wagenaar (2007) for BAC *per se* limits and administrative *per se* license suspension/revocation was based on primary review of statutes by a legal team, and was therefore deemed to be accurate and the most desirable to use in the analyses. These other highway-related laws were considered to be in effect during an entire quarter if they were implemented for at least 2 of the 3 months in the quarter (± up to 5 days).

C. Analysis Method

1. Choice of Statistical Model

The quarters for 16, 17, 18, and 19 year olds were analyzed together using pooled cross-sectional time series analysis through Poisson regression modeling in the SAS GENMOD procedure. The natural log of the interpolated quarterly population for each age group divided by 100,000 was used as an offset term, resulting in analyses of driver fatal crash involvement rates per 100,000 capita (McCullagh & Nelder, 1989). Because there was correlation among the quarters due to both clustering by state and repeated measurements of the age groups over time (geodemographic clustering), generalized estimating equations (GEE) were used to fit the final models and obtain robust (empirical) variances adjusted for the dependencies (Liang & Zeger, 1986). The working correlation structure for the GEEs was approximated by a first-order autoregressive structure, meaning that state age-group quarters closer in time were assumed to be more strongly related than those further away in time. The unit of clustering (i.e., a "subject") was an age group within a state.

A Poisson GEE model was chosen over other alternatives such as negative binomial regression or Poisson models with variances scaled to adjust for over-dispersion based on comparing adjusted rate ratios and confidence limit ratios (CLR; upper 95% confidence limit / lower 95% confidence limit) for the "stronger" teen driver licensing system variable from preliminary analyses replicated under the following six variations in model specification (Table 4):

1. Poisson model without scaled variances or GEE
2. Poisson model with only scaled variances
3. Poisson model with only GEE
4. Poisson model with both scaled variances and GEE
5. Negative binomial model
6. Negative binomial model with GEE

Table 4. Comparison of Teen Driver Licensing Systems Adjusted Rate Ratios and Confidence Limit Ratios across Six Variations in Model Specification

Driver licensing system	Model 1: Poisson		Model 2: Poisson with scaling		Model 3: Poisson with GEE		Model 4: Poisson with scaling and GEE		Model 5: Negative binomial		Model 6: Negative binomial with GEE	
	RR	CLR	RR	CLR	RR	CLR	RR	CLR	RR	CLR	RR	CLR
16 year olds												
1-stage (no LP or IP)‡	—		—		—		—		—		—	
2-stage (LP only < 3 months)	1.04	1.23	1.04	1.23	1.04	1.36	1.04	1.36	1.04	1.22	1.04	1.36
2-stage (LP only ≥ 3 months)	0.88	1.20	0.88	1.21	0.88	1.24	0.88	1.24	0.88	1.20	0.88	1.24
2-stage (IS only 1–2 restrictions)	1.08	1.33	1.08	1.34	1.08	1.47	1.08	1.47	1.08	1.32	1.08	1.48
3-stage with 1 restriction (GDL)	0.85	1.20	0.85	1.21	0.84	1.24	0.84	1.24	0.85	1.20	0.84	1.25
3-stage with 2 restrictions (GDL)	0.74	1.24	0.74	1.24	0.74	1.31	0.74	1.31	0.74	1.23	0.74	1.31
17 year olds												
1-stage (no LP or IP)‡	—		—		—		—		—		—	
2-stage (LP only < 3 months)	0.88	1.21	0.88	1.21	0.88	1.27	0.88	1.27	0.88	1.20	0.88	1.27
2-stage (LP only ≥ 3 months)	0.96	1.18	0.96	1.18	0.96	1.17	0.96	1.17	0.96	1.18	0.96	1.17
2-stage (IS only 1–2 restrictions)	0.94	1.28	0.94	1.28	0.94	1.22	0.94	1.22	0.94	1.27	0.94	1.23
3-stage with 1 restriction (GDL)	0.98	1.18	0.98	1.18	0.98	1.14	0.98	1.14	0.97	1.17	0.97	1.14
3-stage with 2 restrictions (GDL)	0.91	1.20	0.91	1.20	0.91	1.21	0.91	1.21	0.91	1.19	0.91	1.21
18 year olds												
1-stage (no LP or IP)‡	—		—		—		—		—		—	
2-stage (LP only < 3 months)	1.05	1.19	1.05	1.19	1.05	1.18	1.05	1.18	1.04	1.18	1.04	1.19
2-stage (LP only ≥ 3 months)	1.06	1.16	1.06	1.17	1.06	1.21	1.06	1.21	1.06	1.16	1.06	1.21
2-stage (IS only 1–2 restrictions)	1.06	1.25	1.06	1.26	1.06	1.32	1.06	1.32	1.05	1.24	1.05	1.33
3-stage with 1 restriction (GDL)	1.10	1.16	1.10	1.17	1.10	1.15	1.10	1.15	1.10	1.16	1.10	1.14
3-stage with 2 restrictions (GDL)	1.12	1.17	1.12	1.18	1.12	1.21	1.12	1.21	1.12	1.17	1.12	1.20
19 year olds												
1-stage (no LP or IP)‡	—		—		—		—		—		—	
2-stage (LP only < 3 months)	0.96	1.20	0.96	1.20	0.97	1.15	0.97	1.15	0.96	1.19	0.96	1.15
2-stage (LP only ≥ 3 months)	1.05	1.17	1.05	1.17	1.05	1.19	1.05	1.19	1.05	1.16	1.05	1.19
2-stage (IS only 1–2 restrictions)	1.00	1.26	1.00	1.26	1.00	1.28	1.00	1.28	1.00	1.25	1.00	1.29
3-stage with 1 restriction (GDL)	1.00	1.16	1.00	1.17	1.00	1.17	1.00	1.17	0.99	1.16	0.99	1.17
3-stage with 2 restrictions (GDL)	1.05	1.18	1.05	1.18	1.05	1.16	1.05	1.16	1.04	1.17	1.04	1.16

Note. The driver licensing system coding is based on the stronger coding strategy. The adjusted ratio ratios are from models stratified by age and adjusted for highway fuel use, other highway-related laws, other driver licensing systems, state, and state- and age-specific linear trends, seasonality, unemployment, and contemporaneous age 20–24, 25–39, 40–59, and 60 or older driver fatal crash involvement rates. RR = adjusted rate ratio. CLR = confidence limit ratio (upper 95% confidence limit / lower 95% confidence limit). Scaling = adjustment of variance for over-dispersion. GEE = generalized estimating equations. LP = learner permit holding period. IS = intermediate (unsupervised, but initially restricted) licensing stage. GDL = Graduated driver licensing.
‡ = referent category.

In general, all the models tended to give the same results for the rate ratios and similar results for the CLRs (a relative measure of error variability in the estimates). The choice of residual distribution (Poisson or negative binomial) made almost no difference in the CLRs. However, the use of GEE did make a difference to the CLRs. Using GEE tended to increase some of the CLRs slightly, although it also decreased at least one CLR. There was a strong preference for using a GEE or a mixed model with either negative binomial or Poisson residuals based on *a priori* grounds. The logic supporting this choice was that there is a correlation associated with generating a time series of observations within a particular geodemographic subgroup or "cluster" (defined by state and age in this study). The GEE or mixed models are appealing since they account for this correlation. Mixed models work well when there is interest in heterogeneity of effect across the clusters (i.e., random slopes models), but tend to be harder to fit to the data. In this study the heterogeneity of intervention effect is explored by parsing out the individual intervention components. Therefore GEE models were chosen rather than mixed models, because they are easier to fit. Since it made no difference whether the residuals were modeled as negative binomial or Poisson, Poisson seemed to be the logical choice due to parsimony. The GEE approach was chosen for the reasons outlined above and also generally gave the same or slightly larger CLRs, which is preferable when the data are clustered because it indicates that the clustering is being taken into account in the variance estimates.

2. Parameterization of Variables and Adjustments for Confounding

To adjust for differences in driver fatal crash involvement rates across the teen driver age groups, indicator variables representing individual year of age from 16–19 were used in the analyses. To account for the fact that *a priori* differences exist in driver fatal crash rates between states due to different roadway environments, enforcement, weather, licensing rates, and other unmeasured state-specific factors, indicator variables representing state were also used in all analyses. State by age group interaction terms were created to allow for the possibility that state-to-state differences in fatal crash involvement rates also differ across age groups. Given the absence of reliable data on the proportion of teens in each age group who are licensed to drive unsupervised in each state, the state by age group interaction would be expected to account for the fact that different proportions of teens are licensed at different ages across states, which would reduce the effect of any bias caused by the assumption used when coding the GDL core components that teens across all states seek unrestricted licensure as early and quickly as possible. To adjust for confounding from long-term secular trends, a linear parameter representing continuous time (year-quarter) was used in all models. The inclusion of data for a long time period before the first GDL program was implemented in 1996 was intentional in order to allow for stable estimates of preexisting trend to be determined without being completely confounded by the effects associated with implementing teen driver licensing systems. Indicator variables representing quarterly season (i.e., January–March, April–June, July–September, and October–December) were used in all models to remove variation in the crash rates due to seasonal cycles. These trend and seasonal parameters were used to create state by age group interactions to allow for trend and seasonality to be different for each age group within each state (as was deemed necessary given the different slopes shown in Figure 4).

To adjust for historical variability in driver fatal crash involvements associated with macroeconomic factors, quarterly unemployment for each state was also aggregated based on monthly data from the U.S. Bureau of Labor Statistics (1985–2008) and included as a linear term in all analyses. State by age group interactions were created for unemployment to allow the relations between macroeconomic factors and fatal crash rates to vary for each age group within each state. To adjust for general year-to-year changes in driving exposure, annual fuel consumption per driving age resident (age 16 or older) in each state was included as a linear term in all analyses, but without state- or age-specific interactions. To calculate these per capita fuel use rates, annual gallons of motor vehicle fuel consumed for highway use in each state (FHWA, 1997, 1996–2008) were divided by the corresponding mid-year driving-age population estimate for each state. The annual consumption rates were used for each quarter of the year in each state. Allowing the various covariates (except fuel use) to vary by age group and state resulted in large models, but provided the best control for unmeasured historical factors differing between states, between age groups within states, and within state age groups over time that could confound the GDL effect estimates and is an improvement of this study compared to those prior.

Types of overall teen driver licensing systems, GDL core components, and other highway-related laws were represented in the models using indicator variables. To allow for the likely possibility that the effects associated with these factors differed according driver age, age group interactions for these factors were created and used in the models. An important implication of using these interactions is that they result in rate ratios for each factor (i.e., type of overall teen driver licensing system, each GDL core component, and each type of other highway-related law) that are relative to drivers of the same age (i.e., the referent group is drivers of the same age). Overall likelihood ratio tests of factors represented by multiple indicator variables were estimated using custom Wald tests based on the robust variances in the GEE models. However, to maintain comparability across models and because the sample sizes were large enough that there were adequate degrees of freedom for estimating such complex models, no effects or interactions were removed from the models based on the outcomes of the likelihood ratio tests.

Contemporaneous state-specific adult driver fatal crash involvement rates were used in an attempt to further control for residual state-specific variability that might be due to unmeasured factors such as differences in enforcement, weather and roadway conditions, gasoline prices, and changes in other laws that were not coded for this study. Multiple analyses were conducted to determine how the GDL effect estimates varied as a function of whether, and if so which, adult age group fatal crash involvement rates were included in the analyses as covariates. Three different replications of the analyses were conducted for this purpose. The teen driver fatal crash involvement rates were first analyzed without any adult driver fatal crash involvement rates serving as covariates. Next, the teen driver fatal crash involvement rates were analyzed with only the state-specific driver fatal crash involvement rates for adults ages 40–59 included in the models as a covariate. State by age group interactions were created for the adult crash rate covariate to allow for the relation between the 40–59-year-old driver fatal crash involvement rates and those for each teen age group to vary across states. The 40–59-year-old age group was chosen as the initial adult crash rate covariate series because it was the youngest of the adult age groups that would not overlap with 16- and 17-year-old drivers during the 22-year study time period. That is, a person age 17 in 1986 would be age 38 in 2007, so to avoid having overlap among drivers between the teen and adult fatal crash involvement rate series, the 40–59-year-old group was the youngest that could be used.

The ideal of having no overlap between the teen driver fatal crash involvement series and the adult crash rate covariate series may unnecessarily limit the ability to control for unmeasured factors because driver fatal crash involvement rates tend to be more similar between age groups that are closer together (e.g., see Figure 5). Including the driver fatal crash involvement rates of other adult age groups as covariates, even though some portion of them consists of persons who were licensed through the teen driver licensing system being evaluated, might do an even better job of removing variability in the teen driver fatal crash involvement rates due to state-specific unmeasured factors. Therefore, a third replication of the analyses was conducted that included the fatal crash involvement rate for each adult age group (i.e., 20–24, 25–39, 40–59, and 60+) separately with age group by state interactions to allow for the relations between each of the adult fatal crash involvement rates and those for each teen age group to vary across states. The parameter estimates are considered to be meaningfully different across the various models if they differed by 10% or more from the all-adult covariate model parameters.

The age-specific Poisson model for overall teen licensing systems including all adult age group crash rates covariates is specified in Figure 7:

$$\log_e(\text{crashes}) = \beta_0$$

$$\overbrace{+\beta_{\text{Trend}}X_{\text{Trend}} + \sum_{i=1}^{3}\beta_{\text{DSeason}_i}X_{\text{DSeason}_i} + \sum_{j=1}^{50}\beta_{\text{DState}_j}X_{\text{DState}_j}}^{\text{Trend \& Seasonality x State}}$$

$$+\sum_{j=1}^{50}\beta_{\text{Trend*DState}_j}X_{\text{Trend*DState}_j} + \sum_{i=1,\, j=1}^{3,50}\beta_{\text{DSeason*DState}_{ij}}X_{\text{DSeason*DState}_{ij}}$$

$$\overbrace{+\beta_{\text{Unemployment}}X_{\text{Unemployment}} + \sum_{j=1}^{50}\beta_{\text{Unemployment*DState}_j}X_{\text{Unemployment*DState}_j} + \beta_{\text{HighwayFuel}}X_{\text{HighwayFuel}}}^{\text{Unemployment x State \& Annual State Highway Fuel}}$$

$$\overbrace{+\beta_{\text{LearnerOnly}<3\text{mo}}X_{\text{LearnerOnly}<3\text{mo}} + \beta_{\text{LearnerOnly}\geq 3\text{mo}}X_{\text{LearnerOnly}\geq 3\text{mo}} + \beta_{\text{IntermediateOnly}}X_{\text{IntermediateOnly}}}^{\text{Teen Licensing System}}$$

$$+\beta_{\text{GDL1Restriction}}X_{\text{GDL1Restriction}} + \beta_{\text{GDL2Restrictions}}X_{\text{GDL2Restrictions}}$$

Figure 7. Age-Specific Poisson Regression Model for Overall Teen Licensing Systems.

$$
\overbrace{+\beta_{\text{SpeedLimit65MPH}} X_{\text{SpeedLimit65MPH}} + \beta_{\text{SpeedLimit70MPH}} X_{\text{SpeedLimit70MPH}}
+\beta_{\text{SpeedLimit75+MPH}} X_{\text{SpeedLimit75+MPH}} + \beta_{\text{SeatBeltSecondary}} X_{\text{SeatBeltSecondary}}
+\beta_{\text{SeatBeltPrimary}} X_{\text{SeatBeltPrimary}} + \beta_{\text{DrinkingAge21}} X_{\text{DrinkingAge21}} + \beta_{\text{ZeroToleranceAlcohol}} X_{\text{ZeroToleranceAlcohol}}
+\beta_{\text{BAC.10}} X_{\text{BAC.10}} + \beta_{\text{BAC.08}} X_{\text{BAC.08}} + \beta_{\text{AdminPerSe}} X_{\text{AdminPerSe}}}^{\text{Other Traffic Safety Laws}}
$$

$$
\overbrace{+\beta_{\text{Crashes(20-24)}} X_{\text{Crashes(20-24)}} + \beta_{\text{Crashes(25-39)}} X_{\text{Crashes(25-39)}}
+\beta_{\text{Crashes(40-59)}} X_{\text{Crashes(40-59)}} + \beta_{\text{Crashes(60+)}} X_{\text{Crashes(60+)}}}^{\text{Adult Crash Rate Covariates x State}}
$$

$$
+\sum_{j=1}^{50} \beta_{\text{Crashes(20-24)*DState}_j} X_{\text{Crashes(20-24)*DState}_j} + \sum_{j=1}^{50} \beta_{\text{Crashes(25-39)*DState}_j} X_{\text{Crashes(25-39)*DState}_j}
$$

$$
+\sum_{j=1}^{50} \beta_{\text{Crashes(40-59)*DState}_j} X_{\text{Crashes(40-59)*DState}_j} + \sum_{j=1}^{50} \beta_{\text{Crashes(60+)*DState}_j} X_{\text{Crashes(60+)*DState}_j}
$$

$$
\overbrace{+\log_e(\text{population})}^{\text{Offset}}
$$

Figure 7. (continued)

3. Calculation of Net Associations across all Teen Drivers

The analyses described above result in adjusted rate ratios for each type of teen driver licensing system or GDL core component calibration for each individual teen age group. Given the possibility that some teen driver licensing systems are associated with lower crash rates for some teen age groups and higher crash rates for others (i.e., effect modification), it was desirable to create an overall measure that could be used to summarize net associations across all teen drivers. For this purpose, population attributable fractions (for rate ratios ≥ 1) and prevented fractions (for rate ratios < 1) were calculated (Benichou, 2001; Rockhill et al., 1998).

Population attributable fractions calculated in this study indicate the proportions of teen driver fatal crash involvements over a specified time period that would likely not have occurred if a harmful exposure (e.g., late night driving or transporting teen passengers) was eliminated, assuming the exposures are causally related to driver fatal crash incidence (Levine, 2008; Rockhill, Newman, & Weinberg, 1998). Because they indicate the proportions of crashes occurring during a time period that could have been avoided if harmful exposures had been removed, population attributable fractions are appropriate to use for rate ratios greater than 1.0 (Benichou, 2001). However, most of the exposures in this study are coded such that the non-referent values are associated with reduced driving exposure for at least some teen age groups (e.g., older minimum ages for unrestricted driving) and therefore have rate ratios with values less than 1.0. For these protective exposures the appropriate population-level measures of impact are prevented fractions, which indicate the proportions of teen driver fatal crash involvements over a specified time period that were likely averted by the presence of a protective exposure (e.g., restrictions against late night driving or transporting teen passengers), again assuming the exposures are causally-related to driver fatal crash incidence (Benichou, 2001). For factors where the referent values represent none of the exposures (e.g., no nighttime driving restriction), the prevented fractions indicate the proportions of teen driver fatal crash involvements that were likely prevented by having a particular type of teen driver licensing system or GDL core component calibration (e.g., some calibration of a teen passenger restriction vs. no teen passenger restriction). For factors with a referent value representing a different calibration of the component, the prevented fractions indicate the proportions of teen driver fatal crash involvements that were likely prevented by having that particular calibration of the component versus the referent calibration (e.g., an older minimum learner permit age vs. a younger minimum learner permit age).

Driver fatal crash involvements attributable to each type of overall teen driver licensing system and each GDL core component calibration were calculated for purposes of determining the net overall change in teen driver fatal crash involvements across all teen drivers (16–19 years combined) associated with each one, and the types of licensing systems or component calibrations associated with the largest net reductions. Population attributable fractions (PAF_{it}) were calculated as $pd_{it} \times [(RR_i - 1) / RR_i]$, where pd_{it} are the proportions of driver fatal involvements occurring under each teen driver licensing system or GDL core component calibration (i) during the specified time period (t) and RR_i are the corresponding adjusted rate ratio from the final models including all adult driver fatal crash rates as covariates (Formula 4 from Rockhill et al., 1998). Prevented fractions (PF_{it}) were calculated as PAF_{it} / (PAF_{it} – 1) (derived using Formula 11 from Benichou, 2001). For $RR_i \geq 1$, driver fatal crash involvements attributable to each licensing program or component calibration were calculated as PAF_{it} × number of crash involvements$_{it}$,, where t = a single year (used to create an annual average based on the 2003–2007 5-year period), the entire 5-year 2003–2007 period, or the 12-year period from 1996–2007. For $RR_i < 1$, attributable driver fatal crash involvements were calculated as -PF_{it} × number of involvements$_{it}$. Because the resulting attributable fatal crash involvements were positive for harmful exposures and negative for protective exposures, they could be summed to yield net changes in driver fatal crash involvements across all teen drivers for each teen driver licensing system or GDL core component calibration.

The appropriateness of using population attributable fractions/prevented fractions and their potentially limited interpretability in this study deserves some consideration (Levine, 2008; Rockhill et al., 1998). In order for the population attributable fractions and prevented fractions to be interpretable as the proportions of driver fatal crash involvements that are attributable to the various teen licensing systems and program component calibrations studied, the following three conditions must be met: (a) the teen driver licensing system and GDL core component effect estimates must be unbiased; (b) the teen driver licensing systems and GDL core components must be causally-related to teen driver fatal crash involvements; and (c) changes in one GDL core component cannot affect the distributions of the other components (i.e., they are independent). The first and last requirements are probably reasonably satisfied in this study, particularly with regard to the overall analysis of teen driver licensing systems. For the second requirement there is only limited – though generally supportive – empirical evidence that the teen driver licensing systems and GDL core components studied here actually cause changes in teen driver fatal crash involvements. However, there are logical causal mechanisms that could be postulated to support this requirement for the current study since most of the teen driver licensing systems and GDL core components likely reduce driving exposure among teens, which in turn should be associated with lower crash incidence. For example, older minimum licensing ages should be causally related to lower driver fatal crash involvement rates among younger teens because it reduces their driving exposure. The net driver fatal crash involvement estimates in this study are calculated based on population attributable fractions/prevented fractions, and are therefore only valid to the extent that the reader regards the associations reported to be truly causal in nature. While this is probably a reasonable assumption, it is an assumption nonetheless and the reader should be aware of this limitation when attempting to place meaning on these estimates.

One other alternative approach was also used in an attempt to summarize effects across all teen drivers. Specifically, the final adjusted rate ratios were re-estimated in models that excluded age interactions for the teen driver licensing systems and GDL core component factors. These models resulted in adjusted rate ratios for the teen driver licensing systems and GDL core components combined across 16–19 year olds that could be used to characterize the associations across all teen drivers as a group. However, this method assumes a uniform effect across all the age groups and can mask meaningful age-specific associations. For example, because higher proportions of 18 and 19 year olds are licensed to drive unsupervised than 16 and 17 year olds, moderate crash reductions for these younger teens can be hidden in the overall combined rate ratios by small contrary effects among older teens. This is because the older teens contribute more crashes overall to the analyses, which results in these combined rate ratios being weighted towards older teens. Population attributable fractions and prevented fractions were also calculated for these no-age-interaction models and the resulting attributable crash involvement estimates were compared to those from the models that included interactions of age with types of teen driver licensing systems and GDL core component calibrations.

The National Safety Council produces estimates of the average economic costs of unintentional injuries caused by motor vehicles crashes by injury severity level to a victim. Their economic cost estimates include both dollars spent and income not received. Specifically, the cost estimates include wage and productivity losses, medical expenses, administrative expenses, motor vehicle damage, and employers' uninsured costs. Based on the latest data available, they estimate the average economic cost of each motor vehicle-based death to be 1.3 million U.S. dollars (National Safety Council, 2008). Based on the assumption that one teen driver would have been fatally injured in each driver fatal crash avoided, this cost estimate was used to express the net reductions in driver fatal crash involvements across all teen drivers as dollars saved for teen driver licensing systems in general and GDL programs in particular.

CHAPTER 4

IV. RESULTS

A. National Study of Teen Driver Licensing Systems (Aims 1, 2, 5)

The purposes of the analyses in this section were to (a) determine whether the different types of teen driver licensing systems are associated with changes in driver fatal crash involvement rates for 16, 17, 18, and 19 year olds separately (Aim 1); (b) determine the net overall changes in teen driver (16–19 year olds combined) fatal crash involvements associated with implementing these teen driver licensing systems (Aim 2); and (c) compare and describe how the results of the overall teen driver licensing system analysis vary as a function of whether, and which, adult age group driver fatal crash involvement rates are used as contemporaneous covariates to remove state-specific historical variability from unmeasured factors (Aim 5).

Though all teen age groups were analyzed in the same statistical models, the results are described separately for each one in the following four sections for ease of presentation. The results across all teen age groups, including estimates of net association across all teen drivers, are then summarized in a final section. Estimates for trends, seasonality, unemployment, highway fuel use, state, age group, and adult driver fatal crash involvement covariates are not shown for brevity. However, the likelihood ratio tests for all parameters are shown in Table 33 in Appendix A. In the discussions below, the adjusted rate ratios shown in the text are from the "stronger" model in which some minimal criteria were applied to the meaningfulness of learner permit holding periods and driving restriction components for purposes of coding the overall teen licensing systems. In addition, for the results reported in the text all adult driver fatal crash involvement rates were included as covariates, unless stated otherwise. The confidence intervals for the unadjusted rate ratios are also not shown in the tables for brevity. The overall teen licensing system parameter estimates are considered to be meaningfully different across the various models if they differed by 10% or more from the all-adult covariate model parameters.

1. 16 Year Olds Teen Driver Licensing Systems Findings (Aim 1)

During 1986–2007, there were 23,677 16-year-old drivers involved in fatal traffic crashes in the U.S. (Table 5), 65% (n = 15,475) of whom were male. The unadjusted rate ratios comparing the teen driver licensing systems are all less than 1.0, reflecting lower 16-year-old driver fatal crash involvement rates for the various two and three-stage licensing systems compared to one-stage systems. However, these results are confounded by effects associated with trends, seasonality, state-specific differences, unmeasured historical factors, and changes in other highway-related laws. The pattern towards smaller rate ratios for more rigorous licensing systems is particularly confounded because programs with more teen driver licensing components, and those with stricter calibrations of components, tended to be implemented later in time than those with fewer components or less-restrictive calibrations, when downward trend and effects associated with other highway-related law changes would be more pronounced. The adjusted rate ratios obtained after statistically controlling or accounting for these confounding effects are presented in Table 6. Note that not all teen driver licensing systems were directionally consistent with lower driver fatal crash incidence after the covariate adjustments.

The incidence of 16-year-old driver fatal crash involvements was not reliably different during time periods when young teens were required to hold learner permits for less than 3 months as part of two-stage teen licensing systems with only short learner permit holding periods, than during time periods with no special driver licensing requirements for young teens (rate ratio [RR] = 1.04, 95% confidence interval [CI] = 0.89, 1.22). The estimates were similar when adult driver fatal crash involvement rates were not used as covariates, when only those for 40–59 year olds were used, and when the weaker coding strategy was used to categorize the quarters into teen driver licensing systems.

During time periods when young teens were required to hold learner permits for 3 months or longer as part of two-stage teen licensing systems with only longer learner permit holding periods, the incidence of 16-year-old driver fatal crash involvements was reliably 12% lower (RR = 0.88, 95% CI = 0.79, 0.98) than during time periods with no special driver licensing requirements for young teens. The estimates were similar when adult driver fatal crash involvement rates were not used as covariates, when only those for 40–59 year olds were used, and when quarters were classified into licensing systems based on the weaker coding strategy.

Table 5. Unadjusted 16-Year-Old Driver Fatal Crash Involvement Rates for Teen Driver Licensing Systems and Other Highway-Related Laws, United States 1986–2007

Law/driver licensing system	Involvements (Total = 23,677)	Person-years (Total = 84,030,933)	Rate per 100,000 person-years (Overall = 28.2)	Unadjusted rate ratio
Maximum speed limit (MPH)				
55‡	2,807	11,534,952	24.3	—
65	12,866	43,476,235	29.6	1.22
70	6,112	22,416,370	27.3	1.12
≥75	1,892	6,603,376	28.7	1.18
Mandatory seat belt use				
None‡	2,100	5,302,609	39.6	—
Secondary enforcement	13,957	44,301,814	31.5	0.80
Primary enforcement	7,620	34,426,510	22.1	0.56
Minimum legal drinking age of 21				
No‡	1,102	2,889,873	38.1	—
Yes	22,575	81,141,060	27.8	0.73
Zero-tolerance for all ages < 21				
No‡	11,204	33,269,374	33.7	—
Yes	12,473	50,761,559	24.6	0.73
BAC *per se* alcohol limit				
≥ 0.10 or no limit‡	1,506	3,978,836	37.9	—
0.10	13,894	44,415,519	31.3	0.83
0.08	8,277	35,636,578	23.2	0.61
Administrative *per se* for all ages				
No‡	9,010	33,820,109	26.6	—
Yes	14,667	50,210,824	29.2	1.10
Driver licensing system (stronger)[a]				
1-stage (no LP or IP)‡	10,306	27,648,385	37.3	—
2-stage (LP only < 3 months)	2,977	9,394,989	31.7	0.85
2-stage (LP only ≥ 3 months)	2,275	7,596,668	29.9	0.80
2-stage (IS only 1–2 restrictions)	2,676	12,605,188	21.2	0.57
3-stage with 1 restriction (GDL)	3,082	12,791,304	24.1	0.65
3-stage with 2 restrictions (GDL)	2,361	13,994,400	16.9	0.45
Driver licensing system (weaker)[b]				
1-stage (no LP or IP)‡	10,306	27,648,385	37.3	—
2-stage (LP only < 3 months)	2,977	9,394,989	31.7	0.85
2-stage (LP only ≥ 3 months)	1,458	4,777,670	30.5	0.82
2-stage (IS only 1–2 restrictions)	2,021	10,232,153	19.8	0.53
3-stage with 1 restriction (GDL)	3,598	13,819,741	26.0	0.70
3-stage with 2 restrictions (GDL)	3,317	18,157,997	18.3	0.49

Note. MPH = miles per hour. Secondary enforcement = law enforcement cannot stop the vehicle solely for a belt use violation. Primary enforcement = law enforcement can stop the vehicle solely for a belt use violation. BAC = blood alcohol concentration. Administrative *per se* = administrative license suspension/revocation for BAC ≥ the *per se* limit, regardless of age or prior offense history. LP = learner permit holding period. IS = intermediate licensing stage (unsupervised, but initially restricted driving). GDL = Graduated driver licensing.
‡ = referent category.
[a]Only learner permit holding periods lasting 3 months or longer, nighttime driving restrictions starting before 1:00 am, and passenger restrictions allowing no more than 1 passenger < age 20 were deemed valid for being classified as a three-stage system. [b]Any learner permit holding period length of time, any nighttime driving restriction, and any passenger restriction were deemed valid for being classified as a three-stage system.

Table 6. Adjusted 16-Year-Old Driver Fatal Crash Involvement Rate Ratios for Teen Driver Licensing Systems and Other Highway-Related Laws, United States 1986–2007

Law/driver licensing system	No adult crash covariates				Age 40–59 crash covariate only				All adult crash covariates			
	Adjusted rate ratio	95% CI	*p*	CLR	Adjusted rate ratio	95% CI	*p*	CLR	Adjusted rate ratio	95% CI	*p*	CLR
Maximum speed limit 65 MPH	1.03	0.96, 1.12	.3983	1.17	1.02	0.95, 1.10	.6214	1.16	1.02	0.94, 1.10	.6837	1.17
Maximum speed limit 70 MPH	1.07	0.95, 1.21	.2688	1.28	1.03	0.92, 1.16	.5678	1.26	1.01	0.90, 1.13	.8987	1.25
Maximum speed limit ≥75 MPH	1.02	0.89, 1.17	.7917	1.31	1.01	0.89, 1.15	.8932	1.29	1.04	0.92, 1.19	.5160	1.29
Secondary enforcement belt use	0.98	0.89, 1.08	.6590	1.21	0.99	0.90, 1.09	.8461	1.21	0.99	0.90, 1.09	.8406	1.22
Primary enforcement belt use	0.90	0.81, 1.01	.0656†	1.25	0.93	0.83, 1.04	.1798	1.25	0.94	0.83, 1.05	.2726	1.26
Minimum legal drinking age of 21	0.96	0.88, 1.05	.3919	1.19	0.96	0.89, 1.04	.3558	1.16	0.95	0.87, 1.03	.1953	1.18
Zero-tolerance for all ages < 21	1.03	0.95, 1.11	.5229	1.17	1.03	0.96, 1.11	.3851	1.15	1.03	0.97, 1.10	.3601	1.14
BAC limit 0.10	0.92	0.85, 1.01	.0662†	1.19	0.95	0.88, 1.03	.2162	1.18	0.94	0.85, 1.05	.2845	1.24
BAC limit 0.08	0.87	0.76, 0.98	.0278*	1.29	0.89	0.79, 1.00	.0597†	1.28	0.88	0.76, 1.01	.0706†	1.32
Administrative *per se* for all ages	1.10	0.98, 1.24	.1054	1.26	1.08	0.97, 1.20	.1826	1.25	1.05	0.94, 1.16	.3896	1.24
Driver licensing system (stronger)[a]												
2-stage (LP only < 3 months)	1.04	0.89, 1.21	.6050	1.36	1.05	0.90, 1.22	.5666	1.36	1.04	0.89, 1.22	.6031	1.36
2-stage (LP only ≥ 3 months)	0.90	0.81, 1.00	.0528†	1.24	0.89	0.80, 1.00	.0452*	1.24	0.88	0.79, 0.98	.0171*	1.24
2-stage (IS only 1–2 restrictions)	1.11	0.92, 1.34	.2632	1.46	1.11	0.91, 1.35	.2948	1.48	1.08	0.89, 1.30	.4523	1.47
3-stage with 1 restriction (GDL)	0.85	0.77, 0.95	.0037*	1.24	0.85	0.77, 0.95	.0044*	1.24	0.84	0.76, 0.94	.0025*	1.24
3-stage with 2 restrictions (GDL)	0.74	0.64, 0.86	<.0001*	1.33	0.76	0.66, 0.87	<.0001*	1.31	0.74	0.65, 0.85	<.0001*	1.31
Driver licensing system (weaker)[b]												
2-stage (LP only < 3 months)	1.00	0.87, 1.15	.9896	1.31	1.00	0.88, 1.15	.9618	1.31	1.00	0.87, 1.16	.9620	1.33
2-stage (LP only ≥ 3 months)	0.96	0.86, 1.07	.4458	1.24	0.95	0.84, 1.06	.3409	1.26	0.94	0.83, 1.06	.3129	1.28
2-stage (IS only 1–2 restrictions)	1.01	0.88, 1.16	.8764	1.31	1.00	0.87, 1.15	.9705	1.31	0.97	0.86, 1.10	.6603	1.28
3-stage with 1 restriction (GDL)	0.89	0.80, 0.99	.0255*	1.23	0.89	0.81, 0.99	.0336*	1.23	0.87	0.79, 0.97	.0092*	1.22
3-stage with 2 restrictions (GDL)	0.76	0.67, 0.86	<.0001*	1.29	0.77	0.68, 0.86	<.0001*	1.27	0.75	0.67, 0.85	<.0001*	1.27

Note. Referent levels are shown in the prior table; they are excluded here for brevity. The rate ratios are from models stratified by age and adjusted for highway fuel use, other highway-related laws, other driver licensing systems, state, and state- and age-specific linear trends, seasonality, and unemployment. In models with adult covariates, the rate ratios are also adjusted for the contemporaneous state- and age-specific driver fatal crash involvement rates of each included adult age group, as specified. Estimates for other highway-related laws are from the stronger coding models. 95% CI = 95% confidence interval for the adjusted rate ratios. CLR = Confidence limit ratio (ratio of upper and lower confidence limits). MPH = miles per hour. Secondary enforcement = law enforcement cannot stop the vehicle solely for a belt use violation. Primary enforcement = law enforcement can stop the vehicle solely for a belt use violation. BAC = blood alcohol concentration. Administrative *per se* = administrative license suspension/revocation for BAC ≥ the *per se* limit, regardless of age or prior offense history. LP = learner permit holding period. IS = intermediate licensing stage (unsupervised, but initially restricted driving). GDL = Graduated driver licensing.

[a]Only learner permit holding periods lasting 3 months or longer, nighttime driving restrictions starting before 1:00 am, and passenger restrictions allowing no more than 1 passenger < age 20 were deemed valid for being classified as a three-stage system. [b]Any learner permit holding period length of time, any nighttime driving restriction, and any passenger restriction were deemed valid for being classified as a three-stage system.

*$p < .05$ (reliably estimated). †$p < .10$ (marginally reliably estimated).

The incidence of 16-year-old driver fatal crash involvements was not reliably different when young teens were subject to nighttime and/or passenger driving restrictions as part of two-stage teen licensing systems with only intermediate licensing stages (unsupervised, but initially restricted driving) than during periods with no special driver licensing requirements for young teens (RR = 1.08, 95% CI = 0.89, 1.30). The estimates were again similar when adult driver fatal crash involvement rates were not used as covariates and when only those for 40–59 year olds were used. However, when the quarters were classified using the weaker coding strategy, the estimate was closer to the null and remained not statistically reliable (RR = 0.97, 95% CI = 0.86, 1.10).

During time periods when young teens were required to hold learner permits and were also subject to either a nighttime driving restriction or a passenger driving restriction during intermediate licensing stages as part of three-stage GDL teen licensing systems, the incidence of 16-year-old driver fatal crash involvements was reliably 16% lower (RR = 0.84, 95% CI = 0.76, 0.94) than during periods with no special driver licensing requirements for young teens. The estimates were similar when adult driver fatal crash involvement rates were not used as covariates, when only those for 40–59 year olds were used, and under the weaker coding strategy that deemed any learner permit holding period length, nighttime driving restriction start time, or type of passenger restriction in effect to be adequate for quarters to be classified as having three-stage GDL programs.

When young teens were required to hold learner permits and were also subject to both nighttime and a passenger driving restrictions during intermediate licensing stages as part of three-stage GDL teen licensing systems, 16-year-old driver fatal crash incidence was reliably 26% lower (RR = 0.74, 95% CI = 0.65, 0.85) than during periods with no special driver licensing requirements for young teens. The estimates were similar when adult driver fatal crash incidence rates were not used as covariates, when only those for 40–59 year olds were used, and under the weaker coding strategy that deemed having any learner permit holding period length, nighttime driving restriction start time, or type of passenger restriction in effect to be adequate for quarters to be classified as having three-stage GDL programs.

2. 17 Year Olds Teen Driver Licensing Systems Findings (Aim 1)

During 1986–2007, there were 31,261 17-year-old drivers involved in fatal traffic crashes in the U.S. (Table 7), 68% (*n* = 21,405) of whom were male. The unadjusted rate ratios comparing teen driver licensing systems are again all directionally consistent with lower driver fatal crash involvement rates for 17 year olds, but are confounded by the fact that the most complex teen driver licensing systems were implemented later in time when the confounding effects associated with other factors would have been compounded. The rate ratios adjusted for some of these confounding variables — trends, seasonality, state-specific differences, unmeasured historical factors, and the effects associated with other highway-related law changes — are presented in Table 8. The teen driver licensing systems were still all directionally consistent with lower 17-year-old driver fatality incidence after the covariate adjustments.

Table 7. Unadjusted 17-Year-Old Driver Fatal Crash Involvement Rates for Teen Driver Licensing Systems and Other Highway-Related Laws, United States 1986–2007

Law/driver licensing system	Involvements (Total = 31,261)	Person-years (Total = 84,803,766)	Rate per 100,000 person-years (Overall = 36.9)	Unadjusted rate ratio
Maximum speed limit (MPH)				
55‡	4,251	11,706,268	36.3	—
65	16,519	44,055,802	37.5	1.03
70	8,061	22,426,633	35.9	0.99
≥75	2,430	6,615,064	36.7	1.01
Mandatory seat belt use				
None‡	2,531	5,390,031	47.0	—
Secondary enforcement	17,907	44,836,144	39.9	0.85
Primary enforcement	10,823	34,577,591	31.3	0.67
Minimum legal drinking age of 21				
No‡	1,352	2,921,167	46.3	—
Yes	29,909	81,882,599	36.5	0.79
Zero-tolerance for all ages < 21				
No‡	14,274	34,084,192	41.9	—
Yes	16,987	50,719,574	33.5	0.80
BAC *per se* alcohol limit				
≥ 0.10 or no limit‡	1,839	4,082,892	45.0	—
0.10	17,943	45,164,036	39.7	0.88
0.08	11,479	35,556,839	32.3	0.72
Administrative *per se* for all ages				
No‡	12,722	34,441,230	36.9	—
Yes	18,539	50,362,536	36.8	1.00
Driver licensing system (stronger)[a]				
1-stage (no LP or IP)‡	12,749	28,081,827	45.4	—
2-stage (LP only < 3 months)	3,558	9,610,203	37.0	0.82
2-stage (LP only ≥ 3 months)	2,918	7,600,995	38.4	0.85
2-stage (IS only 1–2 restrictions)	3,828	12,840,368	29.8	0.66
3-stage with 1 restriction (GDL)	4,516	12,724,135	35.5	0.78
3-stage with 2 restrictions (GDL)	3,692	13,946,239	26.5	0.58
Driver licensing system (weaker)[b]				
1-stage (no LP or IP)‡	12,749	28,081,827	45.4	—
2-stage (LP only < 3 months)	3,558	9,610,203	37.0	0.82
2-stage (LP only ≥ 3 months)	1,914	4,790,019	40.0	0.88
2-stage (IS only 1–2 restrictions)	3,004	10,466,110	28.7	0.63
3-stage with 1 restriction (GDL)	4,945	13,754,600	36.0	0.79
3-stage with 2 restrictions (GDL)	5,091	18,101,008	28.1	0.62

Note. MPH = miles per hour. Secondary enforcement = law enforcement cannot stop the vehicle solely for a belt use violation. Primary enforcement = law enforcement can stop the vehicle solely for a belt use violation. BAC = blood alcohol concentration. Administrative *per se* = administrative license suspension/revocation for BAC ≥ the *per se* limit, regardless of age or prior offense history. LP = learner permit holding period. IS = intermediate licensing stage (unsupervised, but initially restricted driving). GDL = Graduated driver licensing.
‡ = referent category.
[a]Only learner permit holding periods lasting 3 months or longer, nighttime driving restrictions starting before 1:00 am, and passenger restrictions allowing no more than 1 passenger < age 20 were deemed valid for being classified as a three-stage system. [b]Any learner permit holding period length of time, any nighttime driving restriction, and any passenger restriction were deemed valid for being classified as a three-stage system.

Table 8. Adjusted 17-Year-Old Driver Fatal Crash Involvement Rate Ratios for Teen Driver Licensing Systems and Other Highway-Related Laws, United States 1986–2007

Law/driver licensing system	No adult crash covariates				Age 40–59 crash covariate only				All adult crash covariates			
	Adjusted rate ratio	95% CI	*p*	CLR	Adjusted rate ratio	95% CI	*p*	CLR	Adjusted rate ratio	95% CI	*p*	CLR
Maximum speed limit 65 MPH	0.99	0.94, 1.05	.7591	1.12	0.99	0.93, 1.05	.6421	1.12	1.01	0.96, 1.07	.7058	1.12
Maximum speed limit 70 MPH	1.00	0.90, 1.12	.9323	1.25	0.99	0.88, 1.10	.7853	1.24	1.02	0.92, 1.14	.6929	1.25
Maximum speed limit ≥75 MPH	0.92	0.81, 1.04	.1870	1.28	0.91	0.81, 1.04	.1575	1.28	0.96	0.85, 1.09	.5445	1.27
Secondary enforcement belt use	0.96	0.89, 1.03	.2331	1.16	0.96	0.88, 1.03	.2552	1.17	0.96	0.89, 1.05	.3976	1.18
Primary enforcement belt use	0.85	0.74, 0.97	.0146*	1.31	0.86	0.75, 0.98	.0231*	1.30	0.88	0.77, 1.01	.0712†	1.31
Minimum legal drinking age of 21	1.00	0.93, 1.07	.9342	1.15	0.99	0.92, 1.05	.6618	1.14	0.98	0.92, 1.05	.5291	1.14
Zero-tolerance for all ages < 21	1.02	0.96, 1.08	.5813	1.13	1.03	0.97, 1.09	.3926	1.13	1.03	0.97, 1.10	.3639	1.14
BAC limit 0.10	0.95	0.87, 1.05	.3355	1.21	0.97	0.89, 1.05	.4484	1.18	0.94	0.86, 1.03	.1727	1.19
BAC limit 0.08	0.96	0.85, 1.08	.4743	1.26	0.97	0.87, 1.09	.6306	1.24	0.96	0.86, 1.08	.4918	1.25
Administrative *per se* for all ages	1.07	0.99, 1.16	.1101	1.17	1.09	1.01, 1.18	.0263*	1.16	1.08	0.99, 1.18	.0713†	1.19
Driver licensing system (stronger)[a]												
2-stage (LP only < 3 months)	0.90	0.80, 1.01	.0683†	1.26	0.88	0.80, 0.98	.0177*	1.23	0.88	0.78, 0.99	.0357*	1.27
2-stage (LP only ≥ 3 months)	0.96	0.90, 1.04	.3212	1.16	0.96	0.89, 1.03	.2122	1.15	0.96	0.89, 1.04	.3135	1.17
2-stage (IS only 1–2 restrictions)	0.94	0.85, 1.04	.2391	1.22	0.94	0.86, 1.02	.1540	1.20	0.94	0.85, 1.04	.2093	1.22
3-stage with 1 restriction (GDL)	0.99	0.92, 1.06	.7943	1.15	0.99	0.93, 1.05	.7430	1.13	0.98	0.92, 1.04	.4631	1.14
3-stage with 2 restrictions (GDL)	0.91	0.83, 1.00	.0525†	1.20	0.92	0.84, 1.00	.0497*	1.19	0.91	0.83, 1.01	.0654†	1.21
Driver licensing system (weaker)[b]												
2-stage (LP only < 3 months)	0.90	0.80, 1.02	.0979†	1.27	0.89	0.80, 0.99	.0283*	1.23	0.89	0.78, 1.00	.0530†	1.28
2-stage (LP only ≥ 3 months)	0.99	0.91, 1.08	.8319	1.20	0.98	0.89, 1.08	.7046	1.21	0.99	0.89, 1.10	.8852	1.23
2-stage (IS only 1–2 restrictions)	0.90	0.83, 0.98	.0126*	1.17	0.90	0.83, 0.97	.0078*	1.18	0.91	0.83, 0.99	.0337*	1.20
3-stage with 1 restriction (GDL)	0.98	0.92, 1.04	.4312	1.12	0.97	0.92, 1.03	.3353	1.12	0.96	0.90, 1.03	.2693	1.14
3-stage with 2 restrictions (GDL)	0.93	0.85, 1.02	.1107	1.20	0.93	0.86, 1.01	.0967†	1.18	0.92	0.84, 1.01	.0911†	1.20

Note. Referent levels are shown in the prior table; they are excluded here for brevity. The rate ratios are from models stratified by age and adjusted for highway fuel use, other highway-related laws, other driver licensing systems, state, and state- and age-specific linear trends, seasonality, and unemployment. In models with adult covariates, the rate ratios are also adjusted for the contemporaneous state- and age-specific driver fatal crash involvement rates of each included adult age group, as specified. Estimates for other highway-related laws are from the stronger coding models. 95% CI = 95% confidence interval for the adjusted rate ratios. CLR = Confidence limit ratio (ratio of upper and lower confidence limits). MPH = miles per hour. Secondary enforcement = law enforcement cannot stop the vehicle solely for a belt use violation. Primary enforcement = law enforcement can stop the vehicle solely for a belt use violation. BAC = blood alcohol concentration. Administrative *per se* = administrative license suspension/revocation for BAC ≥ the *per se* limit, regardless of age or prior offense history. LP = learner permit holding period. IS = intermediate licensing stage (unsupervised, but initially restricted driving). GDL = Graduated driver licensing.

[a]Only learner permit holding periods lasting 3 months or longer, nighttime driving restrictions starting before 1:00 am, and passenger restrictions allowing no more than 1 passenger < age 20 were deemed valid for being classified as a three-stage system. [b]Any learner permit holding period length of time, any nighttime driving restriction, and any passenger restriction were deemed valid for being classified as a three-stage system.

*$p < .05$ (reliably estimated). †$p < .10$ (marginally reliably estimated).

During time periods when young teens were required to hold learner permits for less than 3 months as part of two-stage teen licensing systems with only short learner permit holding periods, relative to periods with no special driver licensing requirements for young teens, 17-year-old driver fatal crash incidence was reliably 12% lower (RR = 0.88, 95% CI = 0.78, 0.99). The estimates were similar when adult driver fatal crash involvement rates were not used as covariates, when only those for 40–59 year olds were used, and when quarters were classified into teen driver licensing systems using the weaker coding strategy.

Seventeen-year-old driver fatal crash incidence was not reliably different when young teens were required to hold learner permits for 3 months or longer as part of two-stage teen licensing systems with only longer learner permit holding periods than during periods with no special driver licensing requirements for young teens (RR = 0.96, 95% CI = 0.89, 1.04). The estimates were similar when adult driver fatal crash involvement rates were not used as covariates, when only those for 40–59 year olds were used, and when the quarters were categorized using the weaker coding strategy.

The incidence of 17-year-old driver fatal crash involvements was also not reliably different during times when young teens were subject to nighttime and/or passenger driving restrictions as part of two-stage teen licensing systems with only an intermediate licensing stage than during periods with no special driver licensing requirements for young teens (RR = 0.94, 95% CI = 0.85, 1.04). The estimates were again similar when driver fatal crash incidence rates for adults were not used as covariates, when only those for 40–59 year olds were used, and when the weaker coding strategy was used to categorize the quarters into teen driver licensing systems.

Seventeen-year-old driver fatal crash incidence was not reliably different during time periods when young teens were required to hold learner permits and were also subject to either a nighttime driving restriction or a passenger driving restriction during intermediate licensing stages as part of three-stage GDL teen licensing systems than during periods with no special driver licensing requirements for young teens (RR = 0.98, 95% CI = 0.92, 1.04). The estimates were similar when fatal crash involvement rates for adult drivers were not used as covariates, when only those for 40–59 year olds were used, and under the weaker coding strategy when any learner permit holding period length, nighttime driving restriction start time, or type of passenger restriction in effect were deemed to be adequate for quarters to be classified as having three-stage GDL programs.

When young teens were required to hold learner permits and were also subject to both nighttime and passenger driving restrictions during intermediate licensing stages as part of three-stage GDL teen licensing systems, 17-year-old driver fatal crash incidence was 9% lower (RR = 0.91, 95% CI = 0.83, 1.01), though the estimate was only marginally statistically reliable, than during periods with no special driver licensing requirements for young teens. The estimates were similar when fatal crash involvement rates for adult drivers were not used as covariates, when only those for 40–59 year olds were used, and when quarters were classified using the weaker coding strategy under which any learner permit holding period length, nighttime driving restriction start time, or type of passenger restriction in effect were deemed to be adequate for quarters to be classified as having three-stage GDL programs.

3. 18 Year Olds Teen Driver Licensing Systems Findings (Aim 1)

During 1986–2007, there were 38,631 18-year-old drivers involved in fatal traffic crashes in the U.S. (Table 9), 72% (*n* = 27,839) of whom were male. As was the case for the younger teens, the rate ratios comparing teen driver licensing systems before adjusting for the effects of trends, seasonality, state-specific differences, unmeasured historical factors, and changes in other highway-related laws were all directionally consistent with lower 18-year-old driver fatal crash involvement rates. The adjusted rate ratios that attempt to remove the various sources of confounding are presented in Table 10. Notice that after the covariate adjustments to remove confounding, the various teen driver licensing systems were all directionally consistent with higher 18-year-old driver fatal crash incidence.

The incidence of 18-year-old driver fatal crash involvements was not reliably different during time periods when younger teens were required to hold learner permits for less than 3 months as part of two-stage teen licensing systems with only short learner permit holding periods than during periods with no special driver licensing requirements for younger teens (RR = 1.05, 95% CI = 0.96, 1.13). The estimates were similar when driver fatal crash involvement rates for adults were not used as covariates, when only those for 40–59 year olds were used, and when the weaker coding strategy was used to categorize the quarters into teen driver licensing systems.

Table 9. Unadjusted 18-Year-Old Driver Fatal Crash Involvement Rates for Teen Driver Licensing Systems and Other Highway-Related Laws, United States 1986–2007

Law/driver licensing system	Involvements (Total = 38,631)	Person-years (Total = 83,683,087)	Rate per 100,000 person-years (Overall = 46.2)	Unadjusted rate ratio
Maximum speed limit (MPH)				
55‡	4,943	11,595,403	42.6	—
65	19,854	43,723,976	45.4	1.07
70	10,643	22,012,275	48.4	1.13
≥75	3,191	6,351,434	50.2	1.18
Mandatory seat belt use				
None‡	2,961	5,368,631	55.2	—
Secondary enforcement	21,486	43,990,033	48.8	0.89
Primary enforcement	14,184	34,324,424	41.3	0.75
Minimum legal drinking age of 21				
No‡	1,591	2,840,226	56.0	—
Yes	37,040	80,842,861	45.8	0.82
Zero-tolerance for all ages < 21				
No‡	17,187	33,740,554	50.9	—
Yes	21,444	49,942,534	42.9	0.84
BAC *per se* alcohol limit				
≥ 0.10 or no limit‡	2,267	4,123,292	55.0	—
0.10	21,295	44,411,812	47.9	0.87
0.08	15,069	35,147,983	42.9	0.78
Administrative *per se* for all ages				
No‡	15,390	34,198,517	45.0	—
Yes	23,241	49,484,570	47.0	1.04
Driver licensing system (stronger)[a]				
1-stage (no LP or IP)‡	14,994	27,540,374	54.4	—
2-stage (LP only < 3 months)	4,589	9,456,612	48.5	0.89
2-stage (LP only ≥ 3 months)	3,440	7,340,304	46.9	0.86
2-stage (IS only 1–2 restrictions)	4,637	12,749,647	36.4	0.67
3-stage with 1 restriction (GDL)	5,607	12,703,182	44.1	0.81
3-stage with 2 restrictions (GDL)	5,364	13,892,969	38.6	0.71
Driver licensing system (weaker)[b]				
1-stage (no LP or IP)‡	14,994	27,540,374	54.4	—
2-stage (LP only < 3 months)	4,589	9,456,612	48.5	0.89
2-stage (LP only ≥ 3 months)	2,184	4,613,343	47.3	0.87
2-stage (IS only 1–2 restrictions)	3,676	10,464,807	35.1	0.65
3-stage with 1 restriction (GDL)	6,132	13,541,069	45.3	0.83
3-stage with 2 restrictions (GDL)	7,056	18,066,882	39.1	0.72

Note. MPH = miles per hour. Secondary enforcement = law enforcement cannot stop the vehicle solely for a belt use violation. Primary enforcement = law enforcement can stop the vehicle solely for a belt use violation. BAC = blood alcohol concentration. Administrative *per se* = administrative license suspension/revocation for BAC ≥ the *per se* limit, regardless of age or prior offense history. LP = learner permit holding period. IS = intermediate licensing stage (unsupervised, but initially restricted driving). GDL = Graduated driver licensing.
‡ = referent category.
[a]Only learner permit holding periods lasting 3 months or longer, nighttime driving restrictions starting before 1:00 am, and passenger restrictions allowing no more than 1 passenger < age 20 were deemed valid for being classified as a three-stage system. [b]Any learner permit holding period length of time, any nighttime driving restriction, and any passenger restriction were deemed valid for being classified as a three-stage system.

Table 10. Adjusted 18-Year-Old Driver Fatal Crash Involvement Rate Ratios for Teen Driver Licensing Systems and Other Highway-Related Laws, United States 1986–2007

Law/driver licensing system	No adult crash covariates				Age 40–59 crash covariate only				All adult crash covariates			
	Adjusted rate ratio	95% CI	*p*	CLR	Adjusted rate ratio	95% CI	*p*	CLR	Adjusted rate ratio	95% CI	*p*	CLR
Maximum speed limit 65 MPH	1.04	0.98, 1.10	.2252	1.12	1.03	0.97, 1.09	.3390	1.13	1.04	0.98, 1.10	.2296	1.13
Maximum speed limit 70 MPH	1.07	0.95, 1.19	.2681	1.26	1.04	0.95, 1.15	.3836	1.21	1.04	0.95, 1.13	.4195	1.19
Maximum speed limit ≥75 MPH	0.97	0.82, 1.15	.7254	1.41	0.96	0.81, 1.14	.6818	1.41	1.00	0.83, 1.21	.9961	1.46
Secondary enforcement belt use	1.02	0.94, 1.10	.6665	1.18	1.02	0.94, 1.11	.5730	1.17	1.03	0.95, 1.12	.4951	1.18
Primary enforcement belt use	0.97	0.87, 1.07	.5372	1.23	0.99	0.91, 1.09	.9148	1.21	1.02	0.93, 1.12	.6244	1.20
Minimum legal drinking age of 21	0.96	0.91, 1.01	.0962†	1.11	0.96	0.91, 1.02	.1675	1.11	0.96	0.90, 1.02	.1623	1.13
Zero-tolerance for all ages < 21	1.00	0.95, 1.04	.8370	1.10	1.00	0.95, 1.06	.8708	1.11	1.00	0.96, 1.06	.8671	1.11
BAC limit 0.10	1.03	0.91, 1.17	.6360	1.28	1.06	0.94, 1.19	.3605	1.27	1.08	0.96, 1.22	.2078	1.27
BAC limit 0.08	1.04	0.91, 1.20	.5428	1.31	1.08	0.95, 1.24	.2537	1.31	1.11	0.97, 1.28	.1389	1.32
Administrative *per se* for all ages	1.04	0.97, 1.13	.2783	1.17	1.04	0.98, 1.09	.2146	1.12	1.04	0.99, 1.10	.1376	1.12
Driver licensing system (stronger)[a]												
2-stage (LP only < 3 months)	1.04	0.96, 1.12	.3836	1.17	1.03	0.95, 1.13	.4329	1.18	1.05	0.96, 1.13	.2897	1.18
2-stage (LP only ≥ 3 months)	1.05	0.97, 1.15	.2411	1.19	1.06	0.97, 1.15	.1897	1.19	1.06	0.96, 1.16	.2442	1.21
2-stage (IS only 1–2 restrictions)	1.06	0.93, 1.20	.4056	1.30	1.05	0.92, 1.20	.4387	1.30	1.06	0.92, 1.21	.4476	1.32
3-stage with 1 restriction (GDL)	1.09	1.01, 1.19	.0294*	1.18	1.10	1.02, 1.18	.0107*	1.15	1.10	1.03, 1.18	.0047*	1.15
3-stage with 2 restrictions (GDL)	1.09	0.99, 1.19	.0766†	1.20	1.11	1.01, 1.23	.0269*	1.21	1.12	1.01, 1.23	.0246*	1.21
Driver licensing system (weaker)[b]												
2-stage (LP only < 3 months)	1.03	0.95, 1.12	.4558	1.18	1.03	0.94, 1.13	.5168	1.20	1.04	0.95, 1.14	.3776	1.20
2-stage (LP only ≥ 3 months)	1.03	0.91, 1.15	.6696	1.26	1.03	0.92, 1.15	.6053	1.24	1.02	0.91, 1.16	.7002	1.27
2-stage (IS only 1–2 restrictions)	1.14	1.04, 1.26	.0045*	1.20	1.15	1.04, 1.26	.0062*	1.22	1.16	1.04, 1.28	.0062*	1.23
3-stage with 1 restriction (GDL)	1.10	1.02, 1.19	.0099*	1.16	1.10	1.03, 1.18	.0041*	1.15	1.11	1.04, 1.18	.0025*	1.14
3-stage with 2 restrictions (GDL)	1.07	0.99, 1.16	.0754†	1.17	1.09	1.01, 1.18	.0345*	1.18	1.09	1.01, 1.18	.0266*	1.17

Note. Referent levels are shown in the prior table; they are excluded here for brevity. The rate ratios are from models stratified by age and adjusted for highway fuel use, other highway-related laws, other driver licensing systems, state, and state- and age-specific linear trends, seasonality, and unemployment. In models with adult covariates, the rate ratios are also adjusted for the contemporaneous state- and age-specific driver fatal crash involvement rates of each included adult age group, as specified. Estimates for other highway-related laws are from the stronger coding models. 95% CI = 95% confidence interval for the adjusted rate ratios. CLR = Confidence limit ratio (ratio of upper and lower confidence limits). MPH = miles per hour. Secondary enforcement = law enforcement cannot stop the vehicle solely for a belt use violation. Primary enforcement = law enforcement can stop the vehicle solely for a belt use violation. BAC = blood alcohol concentration. Administrative *per se* = administrative license suspension/revocation for BAC ≥ the *per se* limit, regardless of age or prior offense history. LP = learner permit holding period. IS = intermediate licensing stage (unsupervised, but initially restricted driving). GDL = Graduated driver licensing.

[a]Only learner permit holding periods lasting 3 months or longer, nighttime driving restrictions starting before 1:00 am, and passenger restrictions allowing no more than 1 passenger < age 20 were deemed valid for being classified as a three-stage system. [b]Any learner permit holding period length of time, any nighttime driving restriction, and any passenger restriction were deemed valid for being classified as a three-stage system.

*$p < .05$ (reliably estimated). †$p < .10$ (marginally reliably estimated).

Driver fatal crash involvement incidence for 18 year olds was also not reliably different when younger teens were required to hold learner permits for 3 months or longer as part of two-stage teen licensing systems with only longer learner permit holding periods than during periods with no special driver licensing requirements for younger teens (RR = 1.06, 95% CI = 0.96, 1.16). The estimates were again similar when driver fatal crash involvements for adults were not used as covariates, when only those for 40–59 year olds were used, and when the quarters were classified into teen driver licensing systems based on the weaker coding strategy.

The incidence of 18-year-old driver fatal crash involvements was not reliably different during time periods when younger teens were subject to nighttime and/or passenger driving restrictions as part of two-stage teen licensing systems with only an intermediate licensing stage than during periods with no special driver licensing requirements for younger teens (RR = 1.06, 95% CI = 0.92, 1.21). The estimates were similar when driver fatal crash involvement rates were not used as covariates, when only those for 40–59 year olds were used, and when the quarters were classified into teen driver licensing systems based on the weaker coding strategy.

When younger teens were required to hold learner permits and were also subject to either a nighttime driving restriction or a passenger driving restriction during intermediate licensing stages as part of three-stage GDL teen licensing systems, 18-year-old driver fatal crash incidence was reliably 10% higher (RR = 1.10, 95% CI = 1.03, 1.18) than during periods with no special driver licensing requirements for younger teens. The estimates were similar when driver fatal crash involvement rates of adults were not used as covariates, when only those for 40–59 year olds were used, and under the weaker coding strategy when any learner permit holding period length, nighttime driving restriction start time, or type of passenger restriction in effect were deemed to be adequate for quarters to be classified as having three-stage GDL programs.

During time periods when younger teens were required to hold learner permits and were subject to both nighttime and passenger driving restrictions during intermediate licensing stages as part of three-stage GDL teen licensing systems, 18-year-old driver fatal crash incidence was reliably 12% higher (RR = 1.12, 95% CI = 1.01, 1.23) than during periods with no special driver licensing requirements for younger teens. The estimate was similar when driver fatal crash involvement rates of adults were not used as covariates, when only those for 40–59 year olds were used, and when quarters were classified using the weaker coding strategy under which any learner permit holding period length, nighttime driving restriction start time, or type of passenger restriction in effect were deemed to be adequate for quarters to be classified as having three-stage GDL programs.

4. 19 Year Olds Teen Driver Licensing Systems Findings (Aim 1)

During 1986–2007, there were 38,035 19-year-old drivers involved in fatal traffic crashes in the U.S. (Table 11), 73% (n = 27,935) of whom were male. The unadjusted rate ratios comparing teen driver licensing system were again all directionally consistent with lower driver fatal crash involvement rates for 19 year olds, but are confounded by the fact that the more demanding teen driver licensing systems were implemented later in time. The rate ratios adjusted for trends, seasonality, state-specific differences, unmeasured historical factors, and changes in other highway-related laws are presented in Table 12. After these adjustments were made, there was no longer a consistent directional pattern among the rate ratios, though most were near the null value of 1.0.

The incidence of 19-year-old driver fatal crash involvements was not reliably different during time periods when younger teens were required to hold learner permits for less than 3 months as part of two-stage teen licensing systems with only short learner permit holding periods than during periods with no special driver licensing requirements for younger teens (RR = 0.97, 95% CI = 0.90, 1.04). The estimates were similar when driver fatal crash involvement rates of adults were not used as covariates, when only those for 40–59 year olds were used, and when the quarters were classified into teen driver licensing systems based on the weaker coding strategy.

The incidence of 19-year-old driver fatal crash involvements was also not reliably different when younger teens were required to hold learner permits for 3 months or longer as part of two-stage teen licensing systems with only longer learner permit holding periods than during periods with no special driver licensing requirements for younger teens (RR = 1.05, 95% CI = 0.97, 1.15). The estimates were similar when the driver fatal crash involvement rates of adults were not used as covariates, when only those for 40–59 were used, and when the quarters we classified into teen driver licensing systems based on the weaker coding strategy.

Table 11. Unadjusted 19-Year-Old Driver Fatal Crash Involvement Rates for Teen Driver Licensing Systems and Other Highway-Related Laws, United States 1986–2007

Law/driver licensing system	Involvements (Total = 38,035)	Person-years (Total = 86,433,842)	Rate per 100,000 person-years (Overall = 44.0)	Unadjusted rate ratio
Maximum speed limit (MPH)				
55‡	4,915	12,385,837	39.7	—
65	19,541	45,298,404	43.1	1.09
70	10,461	22,288,529	46.9	1.18
≥75	3,118	6,461,072	48.3	1.22
Mandatory seat belt use				
None‡	2,920	5,697,995	51.2	—
Secondary enforcement	21,125	45,716,358	46.2	0.90
Primary enforcement	13,990	35,019,488	39.9	0.78
Minimum legal drinking age of 21				
No‡	1,572	2,972,114	52.9	—
Yes	36,463	83,461,728	43.7	0.83
Zero-tolerance for all ages < 21				
No‡	17,190	35,858,217	47.9	—
Yes	20,845	50,575,624	41.2	0.86
BAC *per se* alcohol limit				
≥ 0.10 or no limit‡	2,216	4,402,785	50.3	—
0.10	21,027	46,412,549	45.3	0.90
0.08	14,792	35,618,507	41.5	0.83
Administrative *per se* for all ages				
No‡	14,951	35,622,952	42.0	—
Yes	23,084	50,810,890	45.4	1.08
Driver licensing system (stronger)[a]				
1-stage (no LP or IP)‡	14,903	28,925,089	51.5	—
2-stage (LP only < 3 months)	4,513	10,018,124	45.0	0.87
2-stage (LP only ≥ 3 months)	3,432	7,556,241	45.4	0.88
2-stage (IS only 1–2 restrictions)	4,539	13,403,989	33.9	0.66
3-stage with 1 restriction (GDL)	5,506	12,691,011	43.4	0.84
3-stage with 2 restrictions (GDL)	5,142	13,839,387	37.2	0.72
Driver licensing system (weaker)[b]				
1-stage (no LP or IP)‡	14,903	28,925,089	51.5	—
2-stage (LP only < 3 months)	4,513	10,018,124	45.0	0.87
2-stage (LP only ≥ 3 months)	2,241	4,746,805	47.2	0.92
2-stage (IS only 1–2 restrictions)	3,579	11,004,356	32.5	0.63
3-stage with 1 restriction (GDL)	6,022	13,703,881	43.9	0.85
3-stage with 2 restrictions (GDL)	6,777	18,035,587	37.6	0.73

Note. MPH = miles per hour. Secondary enforcement = law enforcement cannot stop the vehicle solely for a belt use violation. Primary enforcement = law enforcement can stop the vehicle solely for a belt use violation. BAC = blood alcohol concentration. Administrative *per se* = administrative license suspension/revocation for BAC ≥ the *per se* limit, regardless of age or prior offense history. LP = learner permit holding period. IS = intermediate licensing stage (unsupervised, but initially restricted driving). GDL = Graduated driver licensing.
‡ = referent category.
[a]Only learner permit holding periods lasting 3 months or longer, nighttime driving restrictions starting before 1:00 am, and passenger restrictions allowing no more than 1 passenger < age 20 were deemed valid for being classified as a three-stage system. [b]Any learner permit holding period length of time, any nighttime driving restriction, and any passenger restriction were deemed valid for being classified as a three-stage system.

Table 12. Adjusted 19-Year-Old Driver Fatal Crash Involvement Rate Ratios for Teen Driver Licensing Systems and Other Highway-Related Laws, United States 1986–2007

Law/driver licensing system	No adult crash covariates				Age 40–59 crash covariate only				All adult crash covariates			
	Adjusted rate ratio	95% CI	*p*	CLR	Adjusted rate ratio	95% CI	*p*	CLR	Adjusted rate ratio	95% CI	*p*	CLR
Maximum speed limit 65 MPH	1.01	0.94, 1.08	.7826	1.14	1.00	0.93, 1.07	.9914	1.15	1.01	0.94, 1.07	.8598	1.14
Maximum speed limit 70 MPH	1.01	0.87, 1.17	.8973	1.34	0.99	0.86, 1.13	.8862	1.31	0.99	0.89, 1.10	.8202	1.24
Maximum speed limit ≥75 MPH	1.01	0.91, 1.13	.8339	1.25	1.00	0.90, 1.12	.9823	1.24	1.02	0.92, 1.14	.6769	1.24
Secondary enforcement belt use	0.97	0.91, 1.04	.4024	1.14	0.98	0.92, 1.05	.6247	1.14	1.00	0.94, 1.06	.9897	1.12
Primary enforcement belt use	0.98	0.88, 1.09	.7034	1.24	1.01	0.92, 1.12	.7773	1.22	1.05	0.97, 1.15	.2326	1.19
Minimum legal drinking age of 21	1.01	0.96, 1.06	.7600	1.11	1.01	0.96, 1.07	.6135	1.11	1.02	0.96, 1.08	.5085	1.12
Zero-tolerance for all ages < 21	0.96	0.91, 1.02	.1898	1.12	0.97	0.92, 1.03	.3310	1.13	0.99	0.94, 1.05	.7722	1.12
BAC limit 0.10	1.04	0.85, 1.26	.7175	1.49	1.06	0.88, 1.28	.5328	1.45	1.01	0.87, 1.19	.8586	1.37
BAC limit 0.08	1.04	0.85, 1.26	.7262	1.49	1.07	0.89, 1.29	.4884	1.45	1.02	0.87, 1.20	.7894	1.39
Administrative *per se* for all ages	0.97	0.89, 1.05	.4509	1.18	0.97	0.90, 1.04	.3921	1.15	0.97	0.90, 1.05	.4318	1.16
Driver licensing system (stronger)[a]												
2-stage (LP only < 3 months)	0.99	0.93, 1.07	.8642	1.15	0.98	0.92, 1.05	.6217	1.14	0.97	0.90, 1.04	.3261	1.15
2-stage (LP only ≥ 3 months)	1.07	0.97, 1.18	.1988	1.23	1.07	0.97, 1.18	.1633	1.22	1.05	0.97, 1.15	.2398	1.19
2-stage (IS only 1–2 restrictions)	1.02	0.90, 1.16	.6996	1.28	1.02	0.90, 1.16	.7072	1.28	1.00	0.88, 1.13	.9833	1.28
3-stage with 1 restriction (GDL)	1.02	0.92, 1.12	.7486	1.22	1.01	0.92, 1.11	.7941	1.20	1.00	0.92, 1.08	.9262	1.17
3-stage with 2 restrictions (GDL)	1.06	0.96, 1.18	.2355	1.23	1.08	0.99, 1.18	.0958†	1.20	1.05	0.97, 1.13	.2083	1.16
Driver licensing system (weaker)[b]												
2-stage (LP only < 3 months)	0.99	0.93, 1.06	.7855	1.14	0.98	0.92, 1.04	.5371	1.13	0.96	0.90, 1.03	.2654	1.14
2-stage (LP only ≥ 3 months)	1.08	0.99, 1.19	.0934†	1.21	1.09	0.99, 1.19	.0843†	1.20	1.07	0.97, 1.17	.2070	1.22
2-stage (IS only 1–2 restrictions)	1.01	0.86, 1.19	.8627	1.38	1.02	0.86, 1.20	.8561	1.41	1.01	0.86, 1.18	.9120	1.37
3-stage with 1 restriction (GDL)	1.05	0.94, 1.16	.3770	1.23	1.05	0.95, 1.16	.3481	1.22	1.03	0.94, 1.12	.5372	1.19
3-stage with 2 restrictions (GDL)	1.03	0.94, 1.13	.4938	1.19	1.04	0.96, 1.13	.3380	1.18	1.02	0.95, 1.09	.6521	1.14

Note. Referent levels are shown in the prior table; they are excluded here for brevity. The rate ratios are from models stratified by age and adjusted for highway fuel use, other highway-related laws, other driver licensing systems, state, and state- and age-specific linear trends, seasonality, and unemployment. In models with adult covariates, the rate ratios are also adjusted for the contemporaneous state- and age-specific driver fatal crash involvement rates of each included adult age group, as specified. Estimates for other highway-related laws are from the stronger coding models. 95% CI = 95% confidence interval for the adjusted rate ratios. CLR = Confidence limit ratio (ratio of upper and lower confidence limits). MPH = miles per hour. Secondary enforcement = law enforcement cannot stop the vehicle solely for a belt use violation. Primary enforcement = law enforcement can stop the vehicle solely for a belt use violation. BAC = blood alcohol concentration. Administrative *per se* = administrative license suspension/revocation for BAC ≥ the *per se* limit, regardless of age or prior offense history. LP = learner permit holding period. IS = intermediate licensing stage (unsupervised, but initially restricted driving). GDL = Graduated driver licensing.

[a]Only learner permit holding periods lasting 3 months or longer, nighttime driving restrictions starting before 1:00 am, and passenger restrictions allowing no more than 1 passenger < age 20 were deemed valid for being classified as a three-stage system. [b]Any learner permit holding period length of time, any nighttime driving restriction, and any passenger restriction were deemed valid for being classified as a three-stage system.

*$p < .05$ (reliably estimated). †$p < .10$ (marginally reliably estimated).

There was also no reliable difference in the driver fatal crash incidence of 19 year olds during time periods when younger teens were subject to nighttime and/or passenger driving restrictions as part of two-stage teen licensing systems with only an intermediate licensing stage than during periods with no special driver licensing requirements for younger teens (RR = 1.00, 95% CI = 0.88, 1.13). The estimates were similar when the driver fatal crash involvement rates of adults were not used as covariates, when only those for 40–59 year olds were used, and when the quarters were classified into teen driver licensing systems based on the weaker coding strategy.

Similarly, when younger teens were required to hold learner permits and were also subject to either a nighttime driving restriction or a passenger driving restriction during intermediate licensing stages as part of three-stage GDL teen licensing systems, the incidence of 19-year-old driver fatal crash involvements was also not reliably different than during periods with no special driver licensing requirements for younger teens (RR = 1.00, 95% CI = 0.92, 1.08). The estimates were similar when adult driver fatal crash involvement rates were not used as covariates, when only those for 40–59 year olds were used, and when the quarters were classified into teen driver licensing programs using the weaker coding strategy for which any learner permit holding period length, nighttime driving restriction start time, or type of passenger restriction in effect were deemed to be adequate for quarters to be classified as having three-stage GDL programs.

Finally, the incidence of 19-year-old driver fatal crash involvements was also not reliably different when younger teens were required to hold learner permits and were subject to both nighttime and passenger driving restrictions during intermediate licensing stages as part of three-stage GDL teen licensing systems than during periods with no special driver licensing requirements for younger teens (RR = 1.05, 95% CI = 0.97, 1.13). The estimate was similar when the driver fatal crash involvement rates for adults were not used as covariates, when only those for 40–59 year olds were used, and when the quarters were classified into teen driver licensing systems using the weaker coding strategy under which any learner permit holding period length, nighttime driving restriction start time, or type of passenger restriction in effect were deemed to be adequate for quarters to be classified as having three-stage GDL programs.

5. Summary of Individual Age Group Teen Driver Licensing Systems Findings (Aim 1) and How Effects Varied as a Function of Methodological Choices (Aim 5)

The results presented in the last four sections addressed whether the different types of teen driver licensing systems were associated with changes in driver fatal crash involvement rates for 16, 17, 18, and 19 year olds separately (Aim 1). In addition, comparisons were made between models to describe how the results of the overall teen driver licensing system analysis varied as a function of whether, and which, adult age group driver fatal crash involvement rates were used as contemporaneous covariates to remove state-specific historical variability from unmeasured factors (Aim 5). The teen driver licensing system estimates were similar (i.e., they did not differ by 10% or more) regardless of whether, and which, adult driver fatal crash involvement rates were used as covariates. Using minimum criteria for considering learner permit holding periods, nighttime driving restrictions, and passenger driving restrictions to be non-trivial for purposes of classifying quarters as having three-stage GDL programs (i.e., the “stronger” coding strategy) also did not make much of a difference in the teen driver licensing system rate ratios (only one teen licensing system rate ratio differed by 10% or more between the stronger and weaker models). Nonetheless, for purposes of summarizing the teen driver licensing systems analyses across all teen drivers (ages 16–19 years), the results from the model using the stronger coding scheme and all adult age group crash rates as covariates were selected for further discussion. To aid in making comparisons, the teen driver licensing system estimates from this model are shown again for all the teen age groups in Table 13.

Summary of 16 Year Olds Teen Driver Licensing Systems Findings (Aim 1). The most salient findings from the teen driver licensing system analyses are in regard to 16 year olds and GDL programs. Specifically, the most stringent three-stage GDL programs that included two restrictions during the intermediate licensing stage were reliably associated with 26% lower 16-year-old driver fatal crash incidence, and the less stringent GDL programs with only one restriction during the intermediate licensing stage were reliably associated with 16% lower incidence, relative to having no special driver licensing system for young teens. Two-stage licensing systems with only non-trivial learner permit holding periods (≥ 3 months) were also reliably associated with 12% lower 16-year-old driver fatal crash incidence. Licensing systems with only short learner permit holding periods (< 3 months) or only intermediate licensing stages (unsupervised, but initially restriction driving) were not reliably associated with changes in 16-year-old driver fatal crash incidence.

Table 13. Summary of 16–19-Year-Old Adjusted Driver Fatal Crash Involvement Rate Ratios for Teen Driver Licensing Systems by Age, United States 1986–2007

Driver licensing system	Adjusted rate ratio	95% confidence interval	*p*	Confidence limit ratio
16 year olds				
1-stage (no LP or IP)‡	—			
2-stage (LP only < 3 months)	1.04	0.89, 1.22	.6031	1.36
2-stage (LP only ≥ 3 months)	0.88	0.79, 0.98	.0171*	1.24
2-stage (IS only 1–2 restrictions)	1.08	0.89, 1.30	.4523	1.47
3-stage with 1 restriction (GDL)	0.84	0.76, 0.94	.0025*	1.24
3-stage with 2 restrictions (GDL)	0.74	0.65, 0.85	<.0001*	1.31
17 year olds				
1-stage (no LP or IP)‡	—			
2-stage (LP only < 3 months)	0.88	0.78, 0.99	.0357*	1.27
2-stage (LP only ≥ 3 months)	0.96	0.89, 1.04	.3135	1.17
2-stage (IS only 1–2 restrictions)	0.94	0.85, 1.04	.2093	1.22
3-stage with 1 restriction (GDL)	0.98	0.92, 1.04	.4631	1.14
3-stage with 2 restrictions (GDL)	0.91	0.83, 1.01	.0654†	1.21
18 year olds				
1-stage (no LP or IP)‡	—			
2-stage (LP only < 3 months)	1.05	0.96, 1.13	.2897	1.18
2-stage (LP only ≥ 3 months)	1.06	0.96, 1.16	.2442	1.21
2-stage (IS only 1–2 restrictions)	1.06	0.92, 1.21	.4476	1.32
3-stage with 1 restriction (GDL)	1.10	1.03, 1.18	.0047*	1.15
3-stage with 2 restrictions (GDL)	1.12	1.01, 1.23	.0246*	1.21
19 year olds				
1-stage (no LP or IP)‡	—			
2-stage (LP only < 3 months)	0.97	0.90, 1.04	.3261	1.15
2-stage (LP only ≥ 3 months)	1.05	0.97, 1.15	.2398	1.19
2-stage (IS only 1–2 restrictions)	1.00	0.88, 1.13	.9833	1.28
3-stage with 1 restriction (GDL)	1.00	0.92, 1.08	.9262	1.17
3-stage with 2 restrictions (GDL)	1.05	0.97, 1.13	.2083	1.16

Note. The adjusted ratio ratios are from the stronger coding model stratified by age and adjusted for highway fuel use, other highway-related laws, other driver licensing systems, state, and state- and age-specific linear trends, seasonality, unemployment, and contemporaneous age 20–24, 25–39, 40–59, and 60 or older driver fatal crash involvement rates. Confidence limit ratio = ratio of upper and lower confidence limits. LP = learner permit holding period. IS = intermediate licensing stage (unsupervised, but initially restricted driving). GDL = Graduated driver licensing.
‡ = referent category.
*$p < .05$ (reliably estimated). †$p < .10$ (marginally reliably estimated)

Summary of 17 Year Olds Teen Driver Licensing Systems Findings (Aim 1). With regard to 17 year olds, the analysis results were less clear. While the adjusted rate ratios for all types of teen driver licensing systems were directionally consistent with lower 17-year-old driver fatal crash incidence compared with not having a special driver licensing system for young teens, only the 12% lower incidence estimate for two-stage systems with short learner permit holding periods (< 3 months) was reliably estimated. However, the estimate for the most stringent three-stage GDL programs with two restrictions during the intermediate licensing stage was marginally reliable (p = .0654), which also suggested (at a lower level of certainty) that such programs were associated with 9% lower 17-year-old driver fatal crash incidence.

Summary of 18 Year Olds Teen Driver Licensing Systems Findings (Aim 1). Contrary to the adjusted rate ratios for 17 year olds, those for 18 year olds indicated that having any type of special teen driver licensing system for younger teens was directionally consistent with higher 18-year-old driver fatal crash incidence compared to not having a special driver licensing system for younger teens. However, the estimates were only statistically reliable for less stringent three-stage GDL programs with one restriction during the intermediate licensing stage (10% higher incidence) and more stringent three-stage GDL programs with two restrictions during the intermediate licensing stage (12% higher incidence).

Summary of 19 Year Olds Teen Driver Licensing Systems Findings (Aim 1). Finally, no particular pattern was apparent in the teen driver licensing system adjusted rate ratios for 19 year olds. None of the teen driver licensing systems for younger teens were reliably associated with changes in 19-year-old fatal crash incidence relative to having no special driver licensing system for younger teens.

6. Teen Driver Licensing Systems Findings across All Teen Drivers 16–19 (Aim 2)

Given that some teen driver licensing systems, three-stage GDL programs in particular, were associated with lower driver fatal crash involvement rates for younger teens (16 and 17 year olds), but higher driver fatal crash involvement rates for some older teens

(18 year olds), it is of interest to know whether such systems are associated with a net overall difference in teen driver (16–19 year old) fatal crash involvements relative to having no special driver licensing system for young teens (Aim 2). This is the most important question addressed by the present study and the remainder of the discussion here aims to address the final purpose of these analyses, which is to determine the net overall changes in teen driver (16–19 year olds combined) fatal crash involvements associated with implementing these teen driver licensing systems. To address this question, the estimated increase or decrease in driver fatal crash involvements attributable to each type of teen driver licensing system was calculated for each teen age group and for three different time spans (Table 14): (a) an annual average (based on the last 5 years), (b) a 5-year period (2003–2007), and (c) the entire 12-year period beginning when the first three-stage U.S. GDL program was implemented (1996–2007). These estimates are based on calculating population attributable fractions (for rate ratios ≥ 1) or prevented fractions (for rate ratios < 1), as discussed earlier, and applying them to these selected time periods (Benichou, 2001; Rockhill et al., 1998). For purposes of the calculations, all teen driver licensing system estimates were used, regardless of their statistical reliability, and it was assumed that the effects were invariant across time. The latter is a strong assumption, so the estimates should be considered to be only approximations of fatal crash involvements attributable to each teen driver licensing system.

Table 14. 16–19-year-old Driver Fatal Crash Involvements Attributable to each Teen Driver Licensing System by Age and Time Span, United States

Driver licensing system	Adjusted rate ratio	1996–2007 population attributable fraction	1996–2007 prevented fraction	Attributable fatal crash involvements		
				Yearly average[a]	2003–2007	1996–2007
16 year olds						
1-stage (no LP or IP)‡	—					
2-stage (LP only < 3 months)	1.04	0.0024	-0.0025	0	1	30
2-stage (LP only ≥ 3 months)	0.88	-0.0237	0.0232	-21	-105	-280
2-stage (IS only 1–2 restrictions)	1.08	0.0060	-0.0060	4	19	72
3-stage with 1 restriction (GDL)	0.84	-0.0469	0.0448	-48	-239	-541
3-stage with 2 restrictions (GDL)	0.74	-0.0686	0.0642	-104	-521	-775
Age group net		-0.1308	0.1237	-169	-845	-1,494
17 year olds						
1-stage (no LP or IP)‡	—					
2-stage (LP only < 3 months)	0.88	-0.0070	0.0070	0	-1	-114
2-stage (LP only ≥ 3 months)	0.96	-0.0067	0.0066	-9	-43	-109
2-stage (IS only 1–2 restrictions)	0.94	-0.0057	0.0056	-4	-20	-93
3-stage with 1 restriction (GDL)	0.98	-0.0066	0.0066	-11	-54	-108
3-stage with 2 restrictions (GDL)	0.91	-0.0214	0.0209	-49	-246	-344
Age group net		-0.0474	0.0468	-73	-363	-768
18 year olds						
1-stage (no LP or IP)‡	—					
2-stage (LP only < 3 months)	1.05	0.0021	-0.0021	0	1	44
2-stage (LP only ≥ 3 months)	1.06	0.0082	-0.0083	14	70	170
2-stage (IS only 1–2 restrictions)	1.06	0.0041	-0.0041	4	20	85
3-stage with 1 restriction (GDL)	1.10	0.0254	-0.0261	53	264	526
3-stage with 2 restrictions (GDL)	1.12	0.0268	-0.0276	80	399	556
Age group net		0.0667	-0.0682	151	753	1,381
19 year olds						
1-stage (no LP or IP)‡	—					
2-stage (LP only < 3 months)	0.97	-0.0017	0.0017	0	-1	-34
2-stage (LP only ≥ 3 months)	1.05	0.0076	-0.0077	13	63	154
2-stage (IS only 1–2 restrictions)	1.00	0.0001	-0.0001	0	0	2
3-stage with 1 restriction (GDL)	1.00	-0.0010	0.0010	-2	-10	-20
3-stage with 2 restrictions (GDL)	1.05	0.0117	-0.0118	34	170	236
Age group net		0.0167	-0.0169	44	222	338
16–19 year olds (combined)						
1-stage (no LP or IP)‡						
2-stage (LP only < 3 months)				0	0	-75
2-stage (LP only ≥ 3 months)				-3	-15	-65
2-stage (IS only 1–2 restrictions)				4	19	67
3-stage with 1 restriction (GDL)				-8	-40	-143
3-stage with 2 restrictions (GDL)				-40	-198	-327
Age 16–19 net				-47	-234	-544

Note. Based on adjusted ratio ratios from the stronger coding model stratified by age and adjusted for highway fuel use, other highway-related laws, other driver licensing systems, state, and state- and age-specific linear trends, seasonality, unemployment, and contemporaneous age 20–24, 25–39, 40–59, and 60 or older driver fatal crash involvement rates. LP = learner permit holding period. IS = intermediate licensing stage (unsupervised, but initially restricted driving). GDL = Graduated driver licensing. Population attributable fraction (PAF_{it}) = $pd_{it} \times [(RR_i - 1) / RR_i]$, where pd_{it} = proportion of fatal involvements occurring under each teen driver licensing system (*i*) during the specified time period (*t*) and RR_i is the adjusted rate ratio (Formula 4 from Rockhill et al., 1998). Prevented fraction (PF_{it}) = $PAF_{it} / (PAF_{it} - 1)$ (derived using Formula 11 from Benichou, 2001). If $RR_i \geq 1$, then attributable fatal crash involvements = $PAF_{it} \times$ number of crash involvements$_{it}$, where *t* = time period specified in each of the last three columns. If $RR_i < 1$, then attributable fatal crash involvements = $-PF_{it} \times$ number of involvements$_{it}$.

[a]Average based on the 5-year period 2003–2007.

‡ = referent category.

Across all 16–19-year-old teen drivers and types of teen driver licensing systems it was estimated that 47 net fewer driver fatal crash involvements annually, 234 net fewer from 2003–2007 (5 years), and 544 net fewer during the 12-year period since the first three-stage U.S. GDL program was implemented were attributable to having specialized teen driver licensing systems. The National Safety Council (2008) estimated that the average fatal crash death results in an economic cost of approximately 1.3 million U.S. dollars. Based on this costing estimate, and assuming that at least one teen would have been killed during each fatal crash involvement, over 705 million U.S. dollars in cost savings were attributable to implementing teen driver licensing systems from 1996–2007.

All the specialized teen driver licensing systems evaluated in this study had negative net attributable driver fatal crash involvement estimates across 16–19 year olds except for two-stage systems with only an intermediate licensing stage, to which an estimated 67 net additional 16–19-year-old driver fatal crash involvements were attributable from 1996–2007. The majority of the net 16–19-year-old driver fatal crash involvement avoidance was attributable to three-stage GDL programs (470 fewer net driver fatal crash involvements), particularly those with two driving restrictions during the intermediate licensing stage (327 fewer net driver fatal crash involvements). Based on the same costing estimate, a cost avoidance of 610 million U.S. dollars is attributable to implementing three-stage GDL programs since the time the first U.S. GDL program was implemented, which is 86% of the overall cost avoidance attributable to implementing specialized teen driver licensing systems of all types from 1996–2007. These estimates take into account that three-stage GDL programs are actually associated with higher driver fatal crash incidence among 18 year olds.

Although the effects associated with the various types of teen driver licensing systems were found to differ according to the specific age of the teens, an alternative approach used to estimate the net effects associated with these programs on 16–19 year olds as a group was to re-run the stronger-coding model without the teen driver licensing system × age interactions. Such a model yields teen driver licensing system effect estimates combined across all the teen age groups that are still adjusted for the same age- and state-specific confounders. The teen driver licensing system estimates from this model (Table 15) were all not statistically reliable: Two-stage systems with only short learner permit holding periods (RR = 0.98, 95% CI = 0.92, 1.04); two-stage systems with only longer learner permit holding periods (RR = 1.00, 95% CI = 0.95, 1.05); two-stage systems with only an intermediate licensing stage (RR = 1.01, 95% CI = 0.93, 1.09); three-stage GDL programs with one restriction during the intermediate licensing stage (RR = 0.99, 95% CI = 0.95, 1.03); and three-stage GDL programs with two restrictions during the intermediate licensing stage (RR = 0.97, 95% CI = 0.92, 1.03).

Based on using the results from the no-age interaction model to calculate net attributable 16–19-year-old driver fatal crash involvements it was estimated that 78 net fewer driver fatal crash involvements annually, 391 net fewer from 2003–2007 (5 years), and 649 net fewer during the 12-year period since the first three-stage U.S. GDL program was implemented were attributable to having specialized teen driver licensing systems. Again, the majority of the net 16–19-year-old driver fatal crash involvement avoidance from 1996–2007 was attributable to three-stage GDL programs (579 fewer net driver fatal crash involvements), particularly those with two driving restrictions during the intermediate licensing stage (432 fewer net driver fatal crash involvements).While the attributable fatal crash involvement savings estimates are somewhat larger than those resulting from the model with the teen driver licensing system × age interactions, the conclusions based on the individual rate ratios are dramatically different. This underscores the importance of allowing effect estimates to vary by age group in studies of teen driver licensing systems in order to accommodate effect modification (interaction) by age.

Table 15. No-Age-Interaction Model Net 16–19-year-old Driver Fatal Crash Involvements Attributable to each Teen Driver Licensing System by Time Span, United States

Driver licensing system	Adjusted rate ratio	95% confidence interval	*p*	Confidence limit ratio	Attributable fatal crash involvements		
					Yearly average[a]	2003–2007	1996–2007
1-stage (no LP or IP)‡	—						
2-stage (LP only < 3 months)	0.98	0.92, 1.04	.5100	1.14	0	-1	-77
2-stage (LP only ≥ 3 months)	1.00	0.95, 1.05	.8561	1.11	-4	-21	-52
2-stage (IS only 1–2 restrictions)	1.01	0.93, 1.09	.7918	1.17	3	13	58
3-stage with 1 restriction (GDL)	0.99	0.95, 1.03	.7131	1.09	-14	-72	-147
3-stage with 2 restrictions (GDL)	0.97	0.92, 1.03	.3907	1.13	-62	-310	-432
Overall net					-78	-391	-649

Note. Based on ratio ratios from the stronger coding model adjusted for highway fuel use, other highway-related laws, other driver licensing systems, state, and state- and age-specific linear trends, seasonality, unemployment, and contemporaneous age 20–24, 25–39, 40–59, and 60 or older driver fatal crash involvement rates. LP = learner permit holding period. IS = intermediate licensing stage (unsupervised, but initially restricted driving). GDL = Graduated driver licensing. Confidence limit ratio = ratio of upper and lower confidence limits.
‡ = referent category.
[a]Average based on the 5-year period 2003–2007.

B. National Study of GDL Program Core Components (Aims 3, 4, 5)

Based on the analyses just presented it is apparent that three-stage GDL programs are associated with lower driver fatal crash incidence among younger teens (16 and 17 year olds) and higher incidence among some older teens (18 year olds), but that overall such programs are associated with a net savings in teen driver (16–19 years old) fatal crash involvements. The purposes of the analyses in this section were to (a) determine whether the seven GDL program core components are associated with changes in driver fatal crash involvement rates for 16, 17, 18, and 19 year olds (separately) and how any effects vary as a function of the specific component calibrations (Aim 3); (b) describe which GDL program core components should be included in programs and how the individual components might be optimally calibrated by determining which component calibrations are associated with the largest net overall reductions in teen driver fatal crash involvements (16–19 year olds combined; Aim 4); and (c) compare and describe how the results of the GDL program core components analysis vary as a function of whether, and which, adult age group driver fatal crash involvement rates are used as contemporaneous covariates to remove state-specific historical variability from unmeasured factors (Aim 5).

The models simultaneously include the ranges of calibrations for all seven GDL program core components, along with all the other factors used to remove confounding (e.g., state- and age-specific trends, seasonality, other highway-related laws, etc.). The adjusted rate ratios from the models indicate the changes in driver fatal crash incidence for each teen age group that are associated with the different GDL program core component calibrations, relative to the referent calibrations for the components (which are often, but not always, the absence of the components), after adjusting for the effects associated with the other GDL program core components and potential confounders. Though all teen age groups were analyzed in the same statistical models, the results are described separately for each one in the following four sections for ease of presentation. This is followed by a summary section organized by GDL program core component in which the results from the all-adult covariate model are summarized for all teen age groups, including estimates of net association for each age group for each component calibration. In the final section, the results for all GDL program core components are summarized across all teen drivers (16–19 years old), including overall estimates of net association for each component calibration.

Estimates for trends, seasonality, unemployment, highway fuel use, state, other highway-related laws, age group, and adult driver fatal crash involvement covariates are not shown for brevity. However, the likelihood ratio tests for all parameters are shown in Table 34 in Appendix A. In the discussions below, the adjusted rate ratios shown in the text are from the model in which all adult driver fatal crash involvement rates were included as covariates, unless stated otherwise. The confidence intervals for the unadjusted rate ratios are also not shown in the tables for brevity. The GDL program core component calibration parameter estimates are considered to be meaningfully different across models if they differed by 10% or more from the all-adult covariate model parameters.

1. 16 Year Olds GDL Program Core Components Findings (Aim 3)

All but two of the unadjusted rate ratios for the GDL program core component calibrations were directionally consistent with lower 16-year-old driver fatal crash involvement rates (Table 16), but these estimates are confounded by trends, seasonality, state-specific differences, unmeasured historical factors, and other highway-related law changes. The adjusted rate ratios that reflect attempts to remove these various sources of confounding are presented in Table 17. The results for each GDL program core component are discussed separately in the following sections.

16 Year Olds Learner Permit Minimum Ages. Relative to time periods when young teens could obtain learner permits at ages younger than 15 years (the most common age being 14 years), 16-year-old driver fatal crash incidence was not different when learner permit minimum ages were from 15 years–15, 5 months (RR = 1.12, 95% CI = 0.91, 1.38), from 15, 6 months–15, 11 months (RR = 0.98, 95% CI = 0.79, 1.23), or 16 years (RR = 0.88, 95% CI = 0.68, 1.13). The estimates were similar when driver fatal crash involvement rates of adults were not used as covariates and when only those for 40–59 year olds were used.

16 Year Olds Learner Permit Holding Period Lengths. Compared to time periods when young teens were not required to hold learner permits for minimum lengths of time, 16-year-old driver fatal crash incidence was not different when they were required to hold learner permits for minimum periods that were less than 3 months (the most common length being 1 month; RR = 1.05, 95% CI = 0.91, 1.20) or 3–4 months (RR = 1.00, 95% CI =

Table 16. Unadjusted 16-Year-Old Driver Fatal Crash Involvement Rates by GDL Program Core Component, United States 1986–2007

GDL core component	Involvements (Total = 23,677)	Person-years (Total = 84,030,933)	Rate per 100,000 person-years (Overall = 28.2)	Unadjusted rate ratio
Learner permit age (minimum)				
< 15 years‡	2,013	5,626,642	35.8	—
15 years–15, 5 months	14,679	46,181,305	31.8	0.89
15, 6 months–15, 11 months	3,624	13,570,609	26.7	0.75
16 years	3,361	18,652,376	18.0	0.50
Learner permit holding period				
None‡	12,327	37,880,537	32.5	—
< 3 months	3,632	11,768,024	30.9	0.95
3–4 months	1,322	5,109,315	25.9	0.80
5–6 months	5,026	24,250,549	20.7	0.64
9–12 months	1,370	5,022,508	27.3	0.84
Supervised driving hours (total)				
None required‡	18,735	59,749,838	31.4	—
≤ 20 hours	559	3,264,875	17.1	0.55
25–35 hours	957	3,578,620	26.7	0.85
40 hours	690	2,853,102	24.2	0.77
50–60 hours	2,736	14,584,498	18.8	0.60
Intermediate stage license age				
No intermediate license stage‡	14,251	40,758,613	35.0	—
< 16 years	1,228	3,410,985	36.0	1.03
16 years–16, 5 months	7,701	34,534,409	22.3	0.64
16, 6 months–17 years	497	5,326,926	9.3	0.27
Nighttime driving restriction (start)				
No nighttime driving restriction‡	14,898	42,465,373	35.1	—
≤ 10:00 pm	1,239	7,633,457	16.2	0.46
11:00 pm	1,374	6,519,386	21.1	0.60
12:00 am	4,985	23,217,081	21.5	0.61
1:00 am	1,181	4,195,636	28.1	0.80
Passenger driving restriction				
No passenger restriction‡	20,133	64,931,828	31.0	—
0 passengers, < 6 months	367	1,345,820	27.3	0.88
0 passengers, ≥ 6 months	1,109	8,121,283	13.7	0.44
1 passenger, ≥ 6 months	1,454	6,749,395	21.5	0.69
2–3 passengers, ≥ 6 months	614	2,882,607	21.3	0.69
Unrestricted license age				
15 years–15, 11 months‡	476	1,356,563	35.1	—
16 years–16, 5 months	14,295	39,058,145	36.6	1.04
16, 6 months–16, 11 months	1,448	5,431,286	26.7	0.76
17 years–17, 5 months	5,020	26,824,729	18.7	0.53
17, 6 months–18 years	2,438	11,360,209	21.5	0.61

Note. GDL = Graduated driver licensing.
‡ = referent category.

Table 17. Adjusted 16-Year-Old Driver Fatal Crash Involvement Rate Ratios by GDL Program Core Component, United States 1986–2007

GDL core component	No adult crash covariates				Age 40–59 crash covariate only				All adult crash covariates			
	Adjusted rate ratio	95% CI	*p*	CLR	Adjusted rate ratio	95% CI	*p*	CLR	Adjusted rate ratio	95% CI	*p*	CLR
Learner permit age (minimum)												
15 years–15, 5 months	1.11	0.90, 1.38	.3206	1.54	1.06	0.85, 1.32	.5852	1.54	1.12	0.91, 1.38	.2895	1.52
15, 6 months–15, 11 months	0.99	0.80, 1.24	.9623	1.55	0.97	0.78, 1.21	.7888	1.54	0.98	0.79, 1.23	.8791	1.56
16 years	0.93	0.72, 1.20	.5845	1.66	0.91	0.71, 1.17	.4717	1.64	0.88	0.68, 1.13	.3181	1.66
Learner permit holding period												
< 3 months	1.03	0.90, 1.17	.6858	1.30	1.04	0.91, 1.19	.5792	1.31	1.05	0.91, 1.20	.5355	1.33
3–4 months	0.98	0.88, 1.09	.7394	1.24	1.00	0.90, 1.11	.9685	1.24	1.00	0.89, 1.13	.9868	1.27
5–6 months	0.87	0.78, 0.98	.0177*	1.25	0.88	0.78, 0.99	.0271*	1.26	0.89	0.78, 1.01	.0659†	1.28
9–12 months	0.70	0.59, 0.84	.0001*	1.43	0.71	0.59, 0.85	.0002*	1.45	0.74	0.62, 0.89	.0010*	1.43
Supervised driving hours (total)												
≤ 20 hours	1.03	0.88, 1.21	.7027	1.38	1.04	0.89, 1.22	.6182	1.38	1.03	0.87, 1.21	.7570	1.39
25–35 hours	0.97	0.87, 1.07	.5064	1.22	0.95	0.86, 1.05	.3029	1.23	0.95	0.85, 1.06	.3694	1.25
40 hours	1.08	0.94, 1.23	.2697	1.30	1.08	0.94, 1.23	.2687	1.31	1.14	1.01, 1.29	.0415*	1.29
50–60 hours	1.00	0.90, 1.11	.9939	1.24	0.99	0.89, 1.11	.9114	1.24	1.02	0.92, 1.13	.6975	1.23
Intermediate stage license age												
< 16 years	1.39	1.15, 1.68	.0006*	1.46	1.40	1.17, 1.69	.0003*	1.44	1.29	1.08, 1.55	.0058*	1.44
16 years–16, 5 months	1.32	1.09, 1.60	.0038*	1.46	1.33	1.09, 1.62	.0048*	1.48	1.18	0.99, 1.41	.0653†	1.43
16, 6 months–17 years	0.92	0.73, 1.16	.4593	1.59	0.90	0.71, 1.15	.3940	1.62	0.77	0.62, 0.96	.0197*	1.56
Nighttime driving restriction												
≤ 10:00 pm	0.81	0.70, 0.93	.0038*	1.34	0.80	0.68, 0.93	.0039*	1.36	0.81	0.69, 0.95	.0097*	1.38
11:00 pm	0.86	0.66, 1.12	.2724	1.70	0.86	0.67, 1.10	.2287	1.64	0.96	0.76, 1.21	.7261	1.58
12:00 am	0.92	0.72, 1.18	.5012	1.63	0.92	0.74, 1.15	.4744	1.56	1.04	0.84, 1.28	.7222	1.52
1:00 am	0.85	0.68, 1.06	.1575	1.56	0.86	0.70, 1.06	.1480	1.52	0.91	0.75, 1.11	.3594	1.49
Passenger driving restriction												
0 passengers, < 6 months	0.96	0.84, 1.10	.5579	1.30	0.96	0.85, 1.08	.4923	1.27	1.02	0.91, 1.15	.7256	1.26
0 passengers, ≥ 6 months	0.92	0.76, 1.10	.3537	1.45	0.91	0.76, 1.10	.3489	1.46	0.91	0.76, 1.09	.2911	1.43
1 passenger, ≥ 6 months	0.82	0.71, 0.94	.0052*	1.33	0.84	0.74, 0.95	.0057*	1.29	0.80	0.72, 0.89	<.0001*	1.24
2–3 passengers, ≥ 6 months	0.99	0.86, 1.14	.8750	1.32	0.98	0.86, 1.11	.7173	1.30	0.98	0.87, 1.11	.7952	1.27
Unrestricted license age												
16 years–16, 5 months	0.95	0.82, 1.09	.4467	1.33	0.93	0.81, 1.07	.2969	1.32	0.89	0.78, 1.02	.1072	1.31
16, 6 months–16, 11 months	0.84	0.69, 1.03	.0884†	1.48	0.83	0.69, 1.00	.0525†	1.45	0.78	0.66, 0.93	.0045*	1.40
17 years–17, 5 months	0.81	0.61, 1.06	.1220	1.73	0.78	0.60, 1.02	.0652†	1.69	0.74	0.56, 0.97	.0293*	1.72
17, 6 months–18 years	0.83	0.65, 1.07	.1554	1.66	0.82	0.65, 1.04	.1041	1.61	0.78	0.61, 1.00	.0473*	1.63

Note. Referent levels are shown in the prior table; they are excluded here for brevity. The rate ratios are from models stratified by age and adjusted for highway fuel use, other highway-related laws, the other GDL components shown in the table, state, and state- and age-specific linear trends, seasonality, and unemployment. In models with adult covariates, the rate ratios are also adjusted for the contemporaneous state- and age-specific driver fatal crash involvement rates of each included adult age group, as specified. GDL = Graduated driver licensing. 95% CI = 95% confidence interval for the adjusted rate ratios. CLR = Confidence limit ratio (ratio of upper and lower confidence limits).
*$p < .05$ (reliably estimated). †$p < .10$ (marginally reliably estimated).

0.89, 1.13). However, 16-year-old driver fatal crash incidence was 11% lower (0.89, 95% CI = 0.78, 1.01) when young teens were required to hold learner permits for 5–6 months, though the estimate was only marginally reliable. In addition, their driver fatal crash incidence was reliably 26% lower (RR = 0.74, 95% CI = 0.62, 0.89) when young teens were required to hold learner permits for 9–12 months. The estimates were similar when driver fatal crash involvement rates of adults were not used as covariates and when only those for 40–59 year olds were used.

16 Year Olds Supervised Driving Hours. Relative to time periods when young teens were not required to completed supervised driving hours, 16-year-old driver fatal crash incidence was not different when young teens were required to complete 20 or fewer hours of supervised driving (the most common requirement being 20 hours; RR = 1.03, 95% CI = 0.87, 1.21), 25–35 hours of supervised driving (RR = 0.95, 95% CI = 0.85, 1.06), or 50–60 hours of supervised driving (RR = 1.02, 95% CI = 0.92, 1.13). However, 16-year-old driver fatal crash incidence was reliably 14% *higher* (RR = 1.14, 95% CI = 1.01, 1.29) when young teens were required to complete 40 hours of supervised driving. Again the estimates were similar when driver fatal crash involvement rates of adults were not used as covariates and when only those for 40–59 year olds were used.

16 Year Olds Intermediate Stage License Ages. Compared to periods when young teens were not subject to intermediate licensing stages, 16-year-old driver fatal crash incidence was reliably 29% higher (RR = 1.29, 95% CI = 1.08, 1.55) when young teens were subject to intermediate licensing stages beginning at ages younger than 16 years (the most common age being 15 years) and 18% higher (RR = 1.18, 95% CI = 0.99, 1.41) when young teens were subject to intermediate licensing stages beginning at ages from 16 years–16, 5 months, though the estimate was only marginally reliable. On the other hand, 16-year-old driver fatal crash incidence was reliably 23% lower (RR = 0.77, 95% CI = 0.62, 0.96) when young teens were subject to intermediate licensing stages beginning at ages from 16, 6 months–17 years.

The estimates for intermediate licensing stages beginning at ages from 16 years–16, 5 months and from 16, 6 months–17 years differed as a function of whether, and which, adult driver fatal crash involvement rates were used as covariates in the analysis. Specifically, the estimate for subjecting young teens to an intermediate licensing stage beginning at ages from 16 years–16, 5 months was stronger and statistically reliable when adult driver fatal crash rates were not used as covariates (RR = 1.32, 95% CI = 1.09, 1.60) and also when only those for 40–59 year olds were used (RR = 1.33, 95% CI = 1.09, 1.62). On the other hand, the estimate for subjecting young teens to an intermediate licensing stage beginning at ages from 16, 6 months–17 years was weaker and not statistically reliable when adult driver fatal crash rates were not used as covariates (RR = 0.92, 95% CI = 0.73, 1.16) and also when only those for 40–59 year olds were used (RR = 0.90, 95% CI = 0.71, 1.15).

16 Year Olds Nighttime Driving Restrictions. Relative to time periods when young teens were not subject to restrictions on the nighttime hours during which they were allowed to drive unsupervised, 16-year-old driver fatal crash incidence was reliably 19% lower (RR = 0.81, 95% CI = 0.69, 0.95) during periods when young teens were subject to nighttime driving restrictions starting at 10:00 pm or earlier (the most common start time being 9:00 pm). However, 16-year-old driver fatal crash incidence was not different during periods when young teens were restricted from driving unsupervised after 11:00 pm (RR = 0.96, 0.76, 1.21), 12:00 am (RR = 1.04, 95% CI = 0.84, 1.28), or 1:00 am (RR = 0.91, 95% CI = 0.75, 1.11).

The estimates for two of the nighttime driving restriction start times differed as a function of whether, and which, adult driver fatal crash involvement rate covariates were used in the model. Specifically, the estimate for nighttime driving restrictions starting at 11:00 pm was stronger, but still not statistically reliable, when adult driver fatal crash involvement rates were not used as covariates (RR = 0.86, 95% CI = 0.66, 1.12) or only those for 40–59 year olds were used (RR = 0.86, 95% CI = 0.67, 1.10). In addition, the estimate for nighttime driving restrictions starting at 12:00 am was in the opposite direction, but still not statistically reliable, when adult driver fatal crash rates were not used as covariates (RR = 0.92, 95% CI = 0.72, 1.18) or only those for 40–59 year olds were used (RR = 0.92, 95% CI = 0.74, 1.15).

16 Year Olds Passenger Driving Restrictions. Compared to time periods when young teens were not subject to restrictions on the number of teen passengers they could transport while driving unsupervised, 16-year-old driver fatal crash incidence was not different when young teens were completely restricted from transporting teen passengers for time periods lasting less than 6 months (the most common time period being 3 months; RR = 1.02, 95% CI = 0.91, 1.15) or 6 months or longer (the most common time period being 6 months; RR =

0.91, 95% CI = 0.76, 1.09). However, when young teens were restricted from transporting more than one teen passenger for time periods of 6 months or longer (the most common time period being 6 months, though 12 months was also common), 16-year-old driver fatal crash incidence was reliably 20% lower (RR = 0.80, 95% CI = 0.72, 0.89). Finally, 16-year-old driver fatal crash incidence was not different when young teens were restricted from transporting more than two or three teen passengers for time periods of 6 months or longer (the most common time period being 12 months; RR = 0.98, 95% CI = 0.87, 1.11). The estimates were similar when driver fatal crash involvement rates of adults were not used as covariates and when only those for 40–59 year olds were used.

16 Year Olds Unrestricted License Ages. Relative to time periods when unrestricted licensure was granted at ages beginning from 15 years–15, 11 months (the most common age being 15 years), 16-year-old driver fatal crash incidence was not different when unrestricted licensure was granted at ages beginning from 16 years–16, 5 months (RR = 0.89, 95% CI = 0.78, 1.02). However, 16-year-old driver fatal crash incidence was reliably 22% lower (RR = 0.78, 95% CI = 0.66, 0.93) when unrestricted licensure was granted at ages beginning from 16, 6 months–16, 11 months, reliably 26% lower (RR = 0.74, 95% CI = 0.56, 0.97) when unrestricted licensure was granted at ages beginning from 17 years–17, 5 months, and reliably 22% lower (RR = 0.78, 95% CI = 0.61, 1.00) when unrestricted licensure was granted at ages beginning from 17, 6 months–18 years. Again the estimates were similar when driver fatal crash involvement rates of adults were not used as covariates and when only those for 40–59 year olds were used.

2. 17 Year Olds GDL Program Core Components Findings (Aim 3)

All but one of the unadjusted rate ratios for the GDL program core component calibrations (Table 18) were directionally consistent with lower 17-year-old driver fatal crash involvement rates, though again these estimates are confounded by the effects of trends, seasonality, state-specific differences, unmeasured historical factors, and other highway-related law changes. The rate ratios adjusted for these sources of confounding are presented in Table 19 and the results for each GDL program core component are discussed separately in the following sections.

17 Year Olds Learner Permit Minimum Ages. Relative to periods of time when young teens could obtain learner permits at ages younger than 15 years, 17-year-old driver fatal crash incidence was not different when learner permit minimum ages were from 15 years–15, 5 months (RR = 1.06, 95% CI = 0.91, 1.22), from 15, 6 months–15, 11 months (RR = 1.03, 95% CI = 0.84, 1.27), or 16 years (RR = 0.93, 95% CI = 0.72, 1.21). The estimates for having a learner permit minimum age of 16 years were in the opposite direction, but still not statistically reliable, when adult driver fatal crash rates were not used as covariates (RR = 1.05, 95% CI = 0.81, 1.36) or only those for 40–59 year olds were used (RR = 1.05, 95% CI = 0.81, 1.35). The estimates for the other learner permit minimum ages were similar across models.

17 Year Olds Learner Permit Holding Period Lengths. Relative to time periods having no minimum learner permit holding periods, 17-year-old driver fatal crash incidence was not different during time periods when young teens were required to hold learner permits

Table 18. Unadjusted 17-Year-Old Driver Fatal Crash Involvement Rates by GDL Program Core Component, United States 1986–2007

GDL core component	Involvements (Total = 31,261)	Person-years (Total = 84,803,766)	Rate per 100,000 person-years (Overall = 36.9)	Unadjusted rate ratio
Learner permit age (minimum)				
< 15 years‡	2,345	5,648,976	41.5	—
15 years–15, 5 months	18,235	46,728,959	39.0	0.94
15, 6 months–15, 11 months	4,775	13,551,349	35.2	0.85
16 years	5,906	18,874,482	31.3	0.75
Learner permit holding period				
None‡	15,753	38,547,937	40.9	—
< 3 months	4,382	11,984,461	36.6	0.89
3–4 months	1,674	5,116,102	32.7	0.80
5–6 months	7,520	24,170,773	31.1	0.76
9–12 months	1,932	4,984,493	38.8	0.95
Supervised driving hours (total)				
None required‡	24,128	60,601,918	39.8	—
≤ 20 hours	904	3,224,170	28.0	0.70
25–35 hours	1,118	3,579,270	31.2	0.78
40 hours	974	2,838,345	34.3	0.86
50–60 hours	4,137	14,560,065	28.4	0.71
Intermediate stage license age				
No intermediate license stage‡	17,640	41,393,795	42.6	—
< 16 years	1,660	3,471,244	47.8	1.12
16 years–16, 5 months	10,657	34,630,114	30.8	0.72
16, 6 months–17 years	1,304	5,308,613	24.6	0.58
Nighttime driving restriction (start)				
No nighttime driving restriction‡	18,434	43,127,133	42.7	—
≤ 10:00 pm	2,229	7,715,706	28.9	0.68
11:00 pm	2,304	6,463,829	35.6	0.83
12:00 am	6,864	23,319,764	29.4	0.69
1:00 am	1,430	4,177,335	34.2	0.80
Passenger driving restriction				
No passenger restriction‡	25,888	65,758,179	39.4	—
0 passengers, < 6 months	481	1,331,084	36.1	0.92
0 passengers, ≥ 6 months	1,807	8,131,184	22.2	0.56
1 passenger, ≥ 6 months	2,092	6,701,404	31.2	0.79
2–3 passengers, ≥ 6 months	993	2,881,916	34.5	0.88
Unrestricted license age				
15 years–15, 11 months‡	612	1,380,225	44.3	—
16 years–16, 5 months	17,054	39,672,968	43.0	0.97
16, 6 months–16, 11 months	2,142	5,412,964	39.6	0.89
17 years–17, 5 months	7,604	27,057,064	28.1	0.63
17, 6 months–18 years	3,849	11,280,546	34.1	0.77

Note. GDL = Graduated driver licensing.
‡ = referent category.

Table 19. Adjusted 17-Year-Old Driver Fatal Crash Involvement Rate Ratios by GDL Program Core Component, United States 1986–2007

GDL core component	No adult crash covariates				Age 40–59 crash covariate only				All adult crash covariates			
	Adjusted rate ratio	95% CI	*p*	CLR	Adjusted rate ratio	95% CI	*p*	CLR	Adjusted rate ratio	95% CI	*p*	CLR
Learner permit age (minimum)												
15 years–15, 5 months	1.03	0.88, 1.20	.7005	1.36	1.05	0.91, 1.21	.4922	1.33	1.06	0.91, 1.22	.4681	1.34
15, 6 months–15, 11 months	1.08	0.89, 1.30	.4324	1.45	1.07	0.90, 1.28	.4494	1.43	1.03	0.84, 1.27	.7533	1.52
16 years	1.05	0.81, 1.36	.7345	1.68	1.05	0.81, 1.35	.7275	1.67	0.93	0.72, 1.21	.5872	1.68
Learner permit holding period												
< 3 months	0.96	0.87, 1.07	.5001	1.24	0.95	0.86, 1.05	.3332	1.22	0.95	0.85, 1.05	.3170	1.23
3–4 months	0.97	0.89, 1.05	.4290	1.19	0.97	0.89, 1.05	.4887	1.18	0.99	0.91, 1.08	.8022	1.19
5–6 months	0.90	0.82, 1.00	.0398*	1.21	0.90	0.82, 0.99	.0342*	1.21	0.91	0.83, 1.01	.0869†	1.23
9–12 months	0.79	0.68, 0.93	.0032*	1.36	0.82	0.70, 0.96	.0114*	1.37	0.83	0.70, 0.97	.0234*	1.39
Supervised driving hours (total)												
≤ 20 hours	1.09	0.99, 1.21	.0829†	1.22	1.07	0.97, 1.18	.1800	1.21	1.04	0.94, 1.15	.4243	1.22
25–35 hours	1.15	0.97, 1.35	.1044	1.39	1.13	0.96, 1.33	.1412	1.39	1.06	0.90, 1.26	.4702	1.41
40 hours	1.16	1.04, 1.28	.0059*	1.23	1.15	1.04, 1.28	.0057*	1.23	1.13	1.02, 1.25	.0155*	1.22
50–60 hours	1.09	1.00, 1.20	.0545†	1.20	1.08	0.98, 1.18	.1062	1.20	1.05	0.94, 1.17	.3863	1.24
Intermediate stage license age												
< 16 years	0.98	0.77, 1.25	.8812	1.62	0.95	0.75, 1.21	.6736	1.61	0.92	0.70, 1.21	.5682	1.73
16 years–16, 5 months	0.99	0.73, 1.34	.9270	1.84	0.99	0.74, 1.34	.9645	1.82	0.99	0.72, 1.37	.9715	1.90
16, 6 months–17 years	1.03	0.76, 1.39	.8534	1.84	1.05	0.78, 1.41	.7604	1.82	1.03	0.75, 1.42	.8369	1.88
Nighttime driving restriction												
≤ 10:00 pm	1.02	0.82, 1.28	.8432	1.57	1.01	0.80, 1.26	.9576	1.57	0.97	0.75, 1.26	.8189	1.69
11:00 pm	1.05	0.75, 1.49	.7674	2.00	1.03	0.74, 1.45	.8453	1.98	0.99	0.69, 1.42	.9418	2.06
12:00 am	1.04	0.75, 1.46	.8083	1.96	1.04	0.75, 1.44	.8122	1.92	1.02	0.72, 1.44	.9283	2.01
1:00 am	1.03	0.74, 1.43	.8737	1.93	1.00	0.72, 1.38	.9772	1.92	0.94	0.66, 1.33	.7219	2.02
Passenger driving restriction												
0 passengers, < 6 months	1.08	0.87, 1.33	.5014	1.53	1.08	0.88, 1.32	.4659	1.50	1.10	0.89, 1.36	.3761	1.53
0 passengers, ≥ 6 months	1.04	0.88, 1.23	.6534	1.41	1.03	0.88, 1.21	.7327	1.38	0.98	0.85, 1.13	.7950	1.32
1 passenger, ≥ 6 months	0.86	0.76, 0.98	.0267*	1.30	0.87	0.77, 0.97	.0154*	1.26	0.88	0.78, 1.00	.0465*	1.28
2–3 passengers, ≥ 6 months	1.06	0.96, 1.17	.2347	1.22	1.06	0.96, 1.17	.2366	1.21	1.03	0.93, 1.14	.5172	1.22
Unrestricted license age												
16 years–16, 5 months	1.23	1.07, 1.41	.0039*	1.32	1.27	1.12, 1.45	.0003*	1.30	1.25	1.07, 1.46	.0043*	1.36
16, 6 months–16, 11 months	1.44	1.20, 1.74	<.0001*	1.45	1.51	1.27, 1.80	<.0001*	1.42	1.53	1.24, 1.89	<.0001*	1.53
17 years–17, 5 months	1.15	0.90, 1.47	.2608	1.63	1.23	0.97, 1.54	.0859†	1.59	1.25	0.95, 1.63	.1075	1.71
17, 6 months–18 years	1.21	0.95, 1.53	.1203	1.60	1.27	1.01, 1.60	.0406*	1.59	1.33	1.02, 1.75	.0370*	1.72

Note. Referent levels are shown in the prior table; they are excluded here for brevity. The rate ratios are from models stratified by age and adjusted for highway fuel use, other highway-related laws, the other GDL components shown in the table, state, and state- and age-specific linear trends, seasonality, and unemployment. In models with adult covariates, the rate ratios are also adjusted for the contemporaneous state- and age-specific driver fatal crash involvement rates of each included adult age group, as specified. GDL = Graduated driver licensing. 95% CI = 95% confidence interval for the adjusted rate ratios. CLR = Confidence limit ratio (ratio of upper and lower confidence limits).

*$p < .05$ (reliably estimated). †$p < .10$ (marginally reliably estimated).

for minimum time periods that were less than 3 months (RR = 0.95, 95% CI = 0.85, 1.05) or only 3–4 months (RR = 0.99, 95% CI = 0.91, 1.08). However, when young teens were required to hold learner permits for 5–6 months, 17-year-old driver fatal crash incidence was 9% lower (RR = 0.91, 0.83, 1.01), though the estimate was only marginally statistically reliable. When young teens were required to hold learner permits for 9–12 months, 17-year-old driver fatal crash incidence was reliably 17% lower (RR = 0.83, 95% CI = 0.70, 0.97). The estimates were similar when adult driver fatal crash involvement rates were not used as covariates and when only those for 40–59 year olds were used.

17 Year Olds Supervised Driving Hours. Compared to time periods when young teens were not required to complete supervised driving hours, 17-year-old driver fatal crash incidence was not different when young teens were required to drive supervised for 20 or fewer hours (RR = 1.04, 95% CI = 0.94, 1.15), 25–35 hours (RR = 1.06, 95% CI = 0.90, 1.26), or 50–60 hours (RR = 1.05, 95% CI = 0.94, 1.17). However, when young teens were required to complete 40 hours of supervised driving practice, 17-year-old driver fatal crash incidence was reliably 13% *higher* (RR = 1.13, 95% CI = 1.02, 1.25). Again the estimates were similar when driver fatal crash involvement rates of adults were not used as covariates and when only those for 40–59 year olds were used.

17 Year Olds Intermediate Stage License Ages. Relative to time periods when young teens were not subject to intermediate licensing stages, 17-year-old driver fatal crash incidence was not different when young teens were subject to intermediate licensing stages beginning at ages younger than 16 years (RR = 0.92, 95% CI = 0.70, 1.21), from 16 years–

16, 5 months (RR = 0.99, 95% CI = 0.72, 1.37), or from 16, 6 months–17 years (RR = 1.03, 95% CI = 0.75, 1.42). The estimates were similar when driver fatal crash involvement rates of adults were not used as covariates and when only those for 40–59 year olds were used.

17 Year Olds Nighttime Driving Restrictions. Compared to time periods when young teens were not subject to restrictions on the nighttime hours during which they were allowed to drive unsupervised, 17-year-old driver fatal crash incidence was not different when young teens were subject to nighttime driving restrictions starting at 10:00 pm or earlier (RR = 0.97, 95% CI = 0.75, 1.26), 11:00 pm (RR = 0.99, 95% CI = 0.69, 1.42), 12:00 am (RR = 1.02, 95% CI = 0.72, 1.44), or 1:00 am (RR = 0.94, 95% CI = 0.66, 1.33). The estimates were again similar when driver fatal crash involvement rates of adults were not used as covariates and when only those for 40–59 year olds were used.

17 Year Olds Passenger Driving Restrictions. Relative to time periods when young teens were not subject to restrictions on the number of teen passengers they could transport while driving unsupervised, 17-year-old driver fatal crash incidence was not different when young teens were completely restricted from transporting teen passengers for time periods lasting less than 6 months (RR = 1.10, 95% CI = 0.89, 1.36) or 6 months or longer (RR = 0.98, 95% CI = 0.85, 1.13). However, when young teens were prohibited from transporting more than one teen passenger for time periods lasting 6 months or longer, 17-year-old driver fatal crash incidence was reliably 12% lower (RR = 0.88, 95% CI = 0.78, 1.00). Seventeen-year old driver fatal crash incidence was not different when young teens were prohibited from transporting more than two or three teen passengers for time periods lasting 6 months or longer (RR = 1.03, 95% CI = 0.93, 1.14). Again the estimates were similar when driver fatal crash involvement rates of adults were not used as covariates and when only those for 40–59 year olds were used.

17 Year Olds Unrestricted License Ages. Compared to time periods when unrestricted licensure was granted at ages beginning from 15 years–15, 11 months, 17-year-old driver fatal crash incidence was reliably 25% higher (RR = 1.25, 95% CI = 1.07, 1.46) when unrestricted licensure was granted at ages beginning from 16 years–16, 5 months. When unrestricted licensure was granted at ages beginning from 16, 6 months–16, 11 months, 17-year-old driver fatal crash incidence was reliably 53% higher (RR = 1.53, 95% CI = 1.24, 1.89). Seventeen-year-old driver fatal crash incidence was not different when unrestricted licensure was granted at ages beginning from 17 years–17, 5 months (RR = 1.25, 95% CI = 0.95, 1.63). Finally, when unrestricted licensure was granted at ages beginning from 17, 6 months–18 years, 17-year-old driver fatal crash incidence was reliably 33% higher (RR = 1.33, 95% CI = 1.02, 1.75). Again the estimates were similar when driver fatal crash involvement rates of adults were not used as covariates and when only those for 40–59 year olds were used.

3. 18 Year Olds GDL Program Core Components Findings (Aim 3)

As was the case for the younger teens, most of the rate ratios for the GDL program core component calibrations were directionally consistent with lower 18-year-old driver fatal crash involvements before adjusting for the confounding effects of trends, seasonality, state-specific differences, unmeasured historical factors, and other highway-related law changes

(Table 20). The adjusted rate ratios that attempt to remove these sources of confounding are presented in Table 21. The results for each GDL core component are discussed separately in the following sections.

18 Year Olds Learner Permit Minimum Ages. Compared to time periods when younger teens were allowed to obtain learner permits at ages younger than 15 years, 18-year-old driver fatal crash incidence was reliably 17% higher (RR = 1.17, 95% CI = 1.00, 1.36) when learner permit minimum ages were from 15 years–15, 5 months and reliably 25% higher (RR = 1.25, 95% CI = 1.06, 1.48) when learner permit minimum ages were from 15, 6 months–15, 11 months. Eighteen-year-old driver fatal crash incidence was also 20% higher (RR = 1.20, 95% CI = 0.98, 1.46) when the learner permit minimum age was 16 years, though the estimate was only marginally reliable. The estimates were similar when driver fatal crash involvement rates of adults were not used as covariates and when only those for 40–59 year olds were used.

18 Year Olds Learner Permit Holding Period Lengths. Relative to time periods when younger teens were not required to hold learner permits for minimum lengths of time, 18-year-old driver fatal crash incidence was not different when younger teens were required to hold learner permits for minimum periods lasting less than 3 months (RR = 1.01, 95% CI = 0.93, 1.10), 3–4 months (RR = 0.99, 95% CI = 0.86, 1.13), 5–6 months (RR = 1.03, 95% CI = 0.92, 1.15), or 9–12 months (RR = 0.85, 95% CI = 0.70, 1.03). The estimates were again similar when driver fatal crash involvement rates of adults were not used as covariates and when only those for 40–59 year olds were used.

Table 20. Unadjusted 18-Year-Old Driver Fatal Crash Involvement Rates by GDL Program Core Component, United States 1986–2007

GDL core component	Involvements (Total = 38,631)	Person-years (Total = 83,683,087)	Rate per 100,000 person-years (Overall = 46.2)	Unadjusted rate ratio
Learner permit age (minimum)				
< 15 years‡	2,772	5,462,912	50.7	—
15 years–15, 5 months	23,258	45,884,697	50.7	1.00
15, 6 months–15, 11 months	5,900	13,352,696	44.2	0.87
16 years	6,701	18,982,783	35.3	0.70
Learner permit holding period				
None‡	18,670	38,005,181	49.1	—
< 3 months	5,550	11,741,452	47.3	0.96
3–4 months	1,963	5,138,023	38.2	0.78
5–6 months	9,904	23,904,845	41.4	0.84
9–12 months	2,544	4,893,587	52.0	1.06
Supervised driving hours (total)				
None required‡	29,274	59,622,421	49.1	—
≤ 20 hours	1,116	3,295,502	33.9	0.69
25–35 hours	1,382	3,559,533	38.8	0.79
40 hours	1,072	2,826,711	37.9	0.77
50–60 hours	5,787	14,378,922	40.2	0.82
Intermediate stage license age				
No intermediate license stage‡	21,051	40,549,188	51.9	—
< 16 years	1,995	3,426,381	58.2	1.12
16 years–16, 5 months	14,022	34,168,315	41.0	0.79
16, 6 months–17 years	1,563	5,539,204	28.2	0.54
Nighttime driving restriction (start)				
No nighttime driving restriction‡	22,005	42,246,791	52.1	—
≤ 10:00 pm	2,727	7,882,020	34.6	0.66
11:00 pm	3,168	6,383,285	49.6	0.95
12:00 am	8,943	23,167,391	38.6	0.74
1:00 am	1,788	4,003,600	44.7	0.86
Passenger driving restriction				
No passenger restriction‡	31,241	64,678,547	48.3	—
0 passengers, < 6 months	554	1,280,625	43.3	0.90
0 passengers, ≥ 6 months	2,781	8,188,644	34.0	0.70
1 passenger, ≥ 6 months	2,868	6,549,581	43.8	0.91
2–3 passengers, ≥ 6 months	1,187	2,985,691	39.8	0.82
Unrestricted license age				
15 years–15, 11 months‡	830	1,335,379	62.2	—
16 years–16, 5 months	20,496	38,907,421	52.7	0.85
16, 6 months–16, 11 months	2,697	5,293,208	51.0	0.82
17 years–17, 5 months	9,811	26,921,669	36.4	0.59
17, 6 months–18 years	4,797	11,225,411	42.7	0.69

Note. GDL = Graduated driver licensing.
‡ = referent category.

Table 21. Adjusted 18-Year-Old Driver Fatal Crash Involvement Rate Ratios by GDL Program Core Component, United States 1986–2007

GDL core component	No adult crash covariates				Age 40–59 crash covariate only				All adult crash covariates			
	Adjusted rate ratio	95% CI	*p*	CLR	Adjusted rate ratio	95% CI	*p*	CLR	Adjusted rate ratio	95% CI	*p*	CLR
Learner permit age (minimum)												
15 years–15, 5 months	1.21	1.02, 1.43	.0249*	1.39	1.21	1.03, 1.42	.0201*	1.38	1.17	1.00, 1.36	.0453*	1.36
15, 6 months–15, 11 months	1.35	1.12, 1.64	.0020*	1.47	1.32	1.10, 1.59	.0029*	1.44	1.25	1.06, 1.48	.0089*	1.40
16 years	1.29	1.03, 1.61	.0279*	1.57	1.25	1.00, 1.55	.0452*	1.55	1.20	0.98, 1.46	.0743†	1.49
Learner permit holding period												
< 3 months	1.00	0.93, 1.09	.9226	1.17	1.00	0.92, 1.08	.9905	1.18	1.01	0.93, 1.10	.7302	1.18
3–4 months	0.98	0.86, 1.11	.7010	1.28	0.99	0.87, 1.12	.8688	1.28	0.99	0.86, 1.13	.8680	1.32
5–6 months	1.00	0.90, 1.11	.9542	1.23	1.01	0.91, 1.11	.8692	1.22	1.03	0.92, 1.15	.6573	1.25
9–12 months	0.82	0.67, 1.01	.0560†	1.51	0.85	0.71, 1.03	.1047	1.46	0.85	0.70, 1.03	.1028	1.47
Supervised driving hours (total)												
≤ 20 hours	1.12	0.97, 1.29	.1353	1.33	1.09	0.94, 1.26	.2403	1.33	1.04	0.89, 1.21	.6480	1.36
25–35 hours	1.10	1.01, 1.19	.0278*	1.18	1.07	0.99, 1.16	.1070	1.17	1.03	0.94, 1.13	.5352	1.20
40 hours	0.92	0.80, 1.05	.2054	1.31	0.91	0.79, 1.04	.1536	1.31	0.90	0.78, 1.05	.1877	1.35
50–60 hours	1.23	1.07, 1.42	.0045*	1.33	1.20	1.05, 1.38	.0065*	1.31	1.20	1.06, 1.37	.0049*	1.29
Intermediate stage license age												
< 16 years	1.11	0.81, 1.51	.5155	1.85	1.08	0.78, 1.49	.6369	1.91	1.08	0.81, 1.44	.5971	1.77
16 years–16, 5 months	1.32	1.03, 1.68	.0275*	1.63	1.31	1.02, 1.68	.0352*	1.65	1.33	1.06, 1.67	.0149*	1.58
16, 6 months–17 years	1.24	0.99, 1.56	.0657†	1.59	1.24	0.97, 1.58	.0854†	1.63	1.26	0.99, 1.62	.0631†	1.64
Nighttime driving restriction												
≤ 10:00 pm	1.01	0.83, 1.23	.9199	1.47	1.00	0.82, 1.22	.9768	1.49	0.97	0.80, 1.18	.7831	1.47
11:00 pm	0.74	0.52, 1.05	.0941†	2.04	0.75	0.52, 1.08	.1189	2.05	0.75	0.53, 1.05	.0919†	1.96
12:00 am	0.79	0.57, 1.11	.1713	1.95	0.81	0.58, 1.13	.2181	1.97	0.81	0.60, 1.11	.1962	1.86
1:00 am	0.80	0.61, 1.05	.1136	1.74	0.80	0.61, 1.07	.1329	1.76	0.80	0.61, 1.04	.0977†	1.71
Passenger driving restriction												
0 passengers, < 6 months	0.87	0.71, 1.07	.1939	1.50	0.88	0.73, 1.06	.1749	1.46	0.87	0.73, 1.04	.1254	1.43
0 passengers, ≥ 6 months	0.97	0.80, 1.17	.7165	1.45	0.99	0.83, 1.17	.8625	1.41	1.00	0.85, 1.17	.9805	1.38
1 passenger, ≥ 6 months	1.00	0.82, 1.23	.9935	1.50	1.01	0.83, 1.23	.9171	1.48	0.99	0.84, 1.18	.9426	1.40
2–3 passengers, ≥ 6 months	0.96	0.87, 1.07	.5044	1.24	0.96	0.86, 1.07	.4834	1.25	0.98	0.87, 1.10	.7076	1.26
Unrestricted license age												
16 years–16, 5 months	0.94	0.84, 1.05	.2853	1.25	0.95	0.84, 1.08	.4384	1.28	0.92	0.81, 1.04	.1824	1.29
16, 6 months–16, 11 months	0.91	0.75, 1.11	.3577	1.49	0.92	0.74, 1.15	.4614	1.56	0.87	0.70, 1.07	.1897	1.53
17 years–17, 5 months	0.93	0.71, 1.22	.6197	1.72	0.94	0.71, 1.26	.6959	1.78	0.88	0.66, 1.18	.4030	1.79
17, 6 months–18 years	0.99	0.76, 1.27	.9071	1.66	0.99	0.75, 1.29	.9210	1.71	0.94	0.71, 1.23	.6437	1.72

Note. Referent levels are shown in the prior table; they are excluded here for brevity. The rate ratios are from models stratified by age and adjusted for highway fuel use, other highway-related laws, the other GDL components shown in the table, state, and state- and age-specific linear trends, seasonality, and unemployment. In models with adult covariates, the rate ratios are also adjusted for the contemporaneous state- and age-specific driver fatal crash involvement rates of each included adult age group, as specified. GDL = Graduated driver licensing. 95% CI = 95% confidence interval for the adjusted rate ratios. CLR = Confidence limit ratio (ratio of upper and lower confidence limits).

**p* < .05 (reliably estimated). †*p* < .10 (marginally reliably estimated).

18 Year Olds Supervised Driving Hours. Compared to time periods when younger teens were not required to complete supervised driving hours, 18-year-old driver fatal crash incidence was not different when younger teens were required to drive supervised for 20 or fewer hours (RR = 1.04, 95% CI = 0.89, 1.21), 25–35 hours (RR = 1.03, 95% CI = 0.94, 1.13), or 40 hours (RR = 0.90, 95% CI = 0.78, 1.05). However, when younger teens were required to complete 50–60 hours of supervised driving, 18-year-old driver fatal crash incidence was reliably 20% higher (RR = 1.20, 95% CI = 1.06, 1.37). Again the estimates were similar when driver fatal crash involvement rates of adults were not used as covariates and when only those for 40–59 year olds were used.

18 Year Olds Intermediate Stage License Ages. Relative to time periods when younger teens were not subject to intermediate licensing stages, 18-year-old driver fatal crash incidence was not reliably different when younger teens were subject to intermediate licensing stages beginning at ages younger than 16 years (RR = 1.08, 95% CI = 0.81, 1.44). However, when younger teens were subject to intermediate licensing stages beginning at ages from 16 years–16, 5 months, 18-year-old driver fatal crash incidence was reliably 33% higher (RR = 1.33, 95% CI = 1.06, 1.67). Furthermore, 18-year-old driver fatal crash incidence was 26% higher (RR = 1.26, 95% CI = 0.99, 1.62) when younger teens were subject to intermediate licensing stages beginning at ages from 16, 6 months–17 years, though the estimate was only marginally reliable. The estimates were similar when driver fatal crash involvement rates of adults were not used as covariates and when only those for 40–59 year olds were used.

18 Year Olds Nighttime Driving Restrictions. Compared to time periods when younger teens were not subject to restrictions on the nighttime hours during which they were allowed to drive unsupervised, 18-year-old driver fatal crash incidence was not different when younger teens were subject to nighttime driving restrictions starting at 10:00 pm or earlier (RR = 0.97, 95% CI = 0.80, 1.18). However, 18-year-old driver fatal crash incidence was 25% lower (RR = 0.75, 95% CI = 0.53, 1.05) when younger teens were subject to nighttime driving restrictions starting at 11:00 pm, though the estimate was only marginally reliable. Eighteen-year-old driver fatal crash incidence was not different when younger teens were subject to nighttime driving restrictions starting at 12:00 am (RR = 0.81, 95% CI = 0.60, 1.11). Finally, their incidence was 20% lower when younger teens were subject to nighttime driving restrictions starting at 1:00 am (RR = 0.80, 95% CI = 0.61, 1.04), though again the estimate was only marginally reliable. The estimates were similar when driver fatal crash involvement rates of adults were not used as covariates and when only those for 40–59 year olds were used.

18 Year Olds Passenger Driving Restrictions. Relative to time periods when younger teens were not restricted with regard to the number of teen passengers they could transport while driving unsupervised, 18-year-old driver fatal crash incidence was not different during periods when younger teens were completely restricted from transporting teen passengers for time periods lasting less than 6 months (RR = 0.87, 95% CI = 0.73, 1.04) or 6 months or longer (RR = 1.00, 95% CI = 0.85, 1.17). Eighteen-year-old driver fatal crash incidence was also not different when younger teens were prohibited from transporting more than one teen passenger for time periods lasting 6 months or longer (RR = 0.99, 95% CI = 0.84, 1.18) or more than two or three teen passengers for time periods lasting 6 months or longer (RR = 0.98, 95% CI = 0.87, 1.10). The estimates were similar when driver fatal crash involvement rates of adults were not used as covariates and when only those for 40–59 year olds were used.

18 Year Olds Unrestricted License Ages. Relative to time periods when younger teens were granted unrestricted licensure at ages beginning from 15 years–15, 11 months, 18-year-old driver fatal crash incidence was not different when unrestricted licensure was granted at any ages from 16–18 years. Specifically, 18-year-old driver fatal crash incidence was not different when younger teens were granted unrestricted licensure at ages beginning from 16 years–16, 5 months (RR = 0.92, 95% CI = 0.81, 1.04), 16, 6 months–16, 11 months (RR = 0.87, 95% CI = 0.70, 1.07), 17 years–17, 5 months (RR = 0.88, 95% CI = 0.66, 1.18), or 17, 6 months–18 years (RR = 0.94, 0.71, 1.23). Again the estimates were similar when driver fatal crash involvement rates of adults were not used as covariates and when only those for 40–59 year olds were used.

4. 19 Year Olds GDL Program Core Components Findings (Aim 3)

The unadjusted rate ratios for the GDL program core component calibrations were again overwhelmingly directionally consistent with lower driver fatal crash involvement rates for 19 year olds (Table 22), but are confounded by the fact that the more severe teen driver licensing system component calibrations were implemented later in time. The rate ratios adjusted for trends, seasonality, state-specific differences, unmeasured historical factors, and other highway-related law changes are presented in Table 23. The results for each GDL program core component are discussed separately in the following sections.

19 Year Olds Learner Permit Minimum Ages. Compared to time periods when younger teens were allowed to obtain learner permits at ages younger than 15 years, 19-year-old driver fatal crash incidence was not reliably different when learner permit minimum ages were from 15 years–15, 5 months (RR = 0.97, 95% CI = 0.87, 1.08), from 15, 6 months–15, 11 months (RR = 0.98, 95% CI = 0.86, 1.11), or age 16 years (RR = 0.87, 95% CI = 0.73, 1.04).

While the estimate for a learner stage minimum age of 15 years–15, 5 months was similar across the models, the estimates for the other two learner permit minimum ages varied as a function of whether, and which, adult driver fatal crash involvement rates were used as covariates in the models. Specifically, the estimate for learner permit minimum ages of 15, 6 months–15, 11 months was in the opposite direction and marginally reliable when adult driver fatal crash involvement rates were not used as covariates (RR = 1.14, 95% CI = 0.99, 1.31). The estimate was also in the opposite direction, but still not statistically reliable when only the driver fatal crash involvement rates for 40–59 year olds were used as a covariate (RR = 1.11, 95% CI = 0.97, 1.27). The estimates for the age 16 learner permit minimum age were also in the opposite direction, but still not statistically reliable, when adult driver fatal crash involvement rates were not used as covariates (RR = 1.06, 95% CI = 0.90, 1.26) and when only those for 40–59 year olds were used (RR = 1.03, 95% CI = 0.87, 1.22).

Table 22. Unadjusted 19-Year-Old Driver Fatal Crash Involvement Rates by GDL Program Core Component, United States 1986–2007

GDL core component	Involvements (Total = 38,035)	Person-years (Total = 86,433,842)	Rate per 100,000 person-years (Overall = 44.0)	Unadjusted rate ratio
Learner permit age (minimum)				
< 15 years‡	2,618	5,634,432	46.5	—
15 years–15, 5 months	23,146	47,575,077	48.7	1.05
15, 6 months–15, 11 months	5,810	13,606,062	42.7	0.92
16 years	6,461	19,618,272	32.9	0.71
Learner permit holding period				
None‡	18,482	39,929,445	46.3	—
< 3 months	5,473	12,417,758	44.1	0.95
3–4 months	1,946	5,103,029	38.1	0.82
5–6 months	9,627	24,083,115	40.0	0.86
9–12 months	2,507	4,900,495	51.2	1.11
Supervised driving hours (total)				
None required‡	29,026	62,408,190	46.5	—
≤ 20 hours	1,027	3,305,984	31.1	0.67
25–35 hours	1,330	3,617,696	36.8	0.79
40 hours	1,124	2,810,126	40.0	0.86
50–60 hours	5,528	14,291,846	38.7	0.83
Intermediate stage license age				
No intermediate license stage‡	21,013	42,592,858	49.3	—
< 16 years	2,023	3,531,497	57.3	1.16
16 years–16, 5 months	13,584	34,696,572	39.2	0.79
16, 6 months–17 years	1,415	5,612,915	25.2	0.51
Nighttime driving restriction (start)				
No nighttime driving restriction‡	21,902	44,321,161	49.4	—
≤ 10:00 pm	2,809	8,103,690	34.7	0.70
11:00 pm	3,068	6,319,019	48.6	0.98
12:00 am	8,603	23,588,557	36.5	0.74
1:00 am	1,653	4,101,415	40.3	0.82
Passenger driving restriction				
No passenger restriction‡	30,936	67,473,559	45.8	—
0 passengers, < 6 months	521	1,276,044	40.8	0.89
0 passengers, ≥ 6 months	2,638	8,146,604	32.4	0.71
1 passenger, ≥ 6 months	2,742	6,546,781	41.9	0.91
2–3 passengers, ≥ 6 months	1,198	2,990,854	40.1	0.87
Unrestricted license age				
15 years–15, 11 months‡	887	1,394,720	63.6	—
16 years–16, 5 months	20,423	40,885,687	50.0	0.79
16, 6 months–16, 11 months	2,677	5,414,068	49.4	0.78
17 years–17, 5 months	9,533	27,422,242	34.8	0.55
17, 6 months–18 years	4,515	11,317,125	39.9	0.63

Note. GDL = Graduated driver licensing.
‡ = referent category.

Table 23. Adjusted 19-Year-Old Driver Fatal Crash Involvement Rate Ratios by GDL Program Core Component, United States 1986–2007

GDL core component	No adult crash covariates				Age 40–59 crash covariate only				All adult crash covariates			
	Adjusted rate ratio	95% CI	*p*	CLR	Adjusted rate ratio	95% CI	*p*	CLR	Adjusted rate ratio	95% CI	*p*	CLR
Learner permit age (minimum)												
15 years–15, 5 months	1.03	0.92, 1.15	.6344	1.26	1.03	0.92, 1.16	.5912	1.26	0.97	0.87, 1.08	.5593	1.24
15, 6 months–15, 11 months	1.14	0.99, 1.31	.0703†	1.32	1.11	0.97, 1.27	.1346	1.31	0.98	0.86, 1.11	.7050	1.29
16 years	1.06	0.90, 1.26	.4648	1.39	1.03	0.87, 1.22	.7016	1.39	0.87	0.73, 1.04	.1266	1.42
Learner permit holding period												
< 3 months	1.00	0.92, 1.07	.9362	1.16	0.99	0.91, 1.07	.7816	1.17	0.97	0.90, 1.05	.4994	1.17
3–4 months	1.00	0.91, 1.10	.9538	1.21	1.01	0.92, 1.11	.8661	1.20	1.02	0.92, 1.12	.7514	1.21
5–6 months	1.08	0.97, 1.20	.1810	1.24	1.08	0.97, 1.20	.1510	1.24	1.07	0.96, 1.19	.2154	1.24
9–12 months	0.99	0.86, 1.15	.9348	1.34	1.03	0.89, 1.19	.6995	1.33	1.07	0.92, 1.23	.3753	1.33
Supervised driving hours (total)												
≤ 20 hours	1.34	1.15, 1.57	.0002*	1.37	1.31	1.12, 1.53	.0009*	1.37	1.22	1.09, 1.37	.0006*	1.25
25–35 hours	1.07	0.99, 1.16	.1002	1.18	1.05	0.97, 1.13	.1955	1.16	1.02	0.95, 1.10	.5179	1.16
40 hours	1.20	1.07, 1.33	.0013*	1.24	1.18	1.06, 1.31	.0021*	1.23	1.14	1.03, 1.26	.0132*	1.23
50–60 hours	1.21	1.08, 1.36	.0011*	1.26	1.19	1.07, 1.32	.0012*	1.24	1.16	1.04, 1.29	.0060*	1.23
Intermediate stage license age												
< 16 years	0.89	0.70, 1.14	.3641	1.64	0.87	0.69, 1.10	.2370	1.60	0.87	0.69, 1.08	.2066	1.56
16 years–16, 5 months	1.01	0.80, 1.27	.9291	1.58	0.99	0.80, 1.22	.9030	1.53	0.99	0.82, 1.19	.9099	1.45
16, 6 months–17 years	0.71	0.53, 0.96	.0267*	1.82	0.70	0.53, 0.92	.0101*	1.74	0.73	0.57, 0.93	.0117*	1.64
Nighttime driving restriction												
≤ 10:00 pm	1.22	1.03, 1.46	.0248*	1.42	1.24	1.05, 1.46	.0118*	1.39	1.14	0.97, 1.34	.1077	1.38
11:00 pm	1.09	0.86, 1.38	.4714	1.59	1.14	0.93, 1.41	.2166	1.52	1.08	0.87, 1.34	.4885	1.53
12:00 am	1.09	0.85, 1.39	.5078	1.63	1.14	0.92, 1.43	.2382	1.56	1.10	0.89, 1.37	.3656	1.54
1:00 am	1.19	0.95, 1.48	.1328	1.56	1.23	1.00, 1.51	.0526†	1.51	1.16	0.94, 1.44	.1579	1.52
Passenger driving restriction												
0 passengers, < 6 months	1.08	0.89, 1.31	.4343	1.47	1.06	0.89, 1.27	.4945	1.42	1.06	0.89, 1.26	.5357	1.42
0 passengers, ≥ 6 months	0.99	0.89, 1.10	.8262	1.23	1.00	0.91, 1.10	.9580	1.20	1.01	0.92, 1.10	.9117	1.19
1 passenger, ≥ 6 months	1.02	0.91, 1.15	.6851	1.26	1.03	0.91, 1.15	.6690	1.26	1.03	0.94, 1.14	.5052	1.22
2–3 passengers, ≥ 6 months	0.99	0.89, 1.10	.8434	1.24	1.00	0.90, 1.11	.9513	1.23	1.00	0.90, 1.12	.9736	1.24
Unrestricted license age												
16 years–16, 5 months	0.80	0.72, 0.89	<.0001*	1.23	0.80	0.72, 0.88	<.0001*	1.22	0.80	0.73, 0.88	<.0001*	1.21
16, 6 months–16, 11 months	0.64	0.55, 0.74	<.0001*	1.33	0.64	0.56, 0.74	<.0001*	1.32	0.65	0.58, 0.73	<.0001*	1.27
17 years–17, 5 months	0.60	0.47, 0.78	<.0001*	1.66	0.60	0.47, 0.76	<.0001*	1.63	0.63	0.51, 0.77	<.0001*	1.49
17, 6 months–18 years	0.64	0.52, 0.79	<.0001*	1.52	0.62	0.51, 0.77	<.0001*	1.51	0.65	0.53, 0.79	<.0001*	1.49

Note. Referent levels are shown in the prior table; they are excluded here for brevity. The rate ratios are from models stratified by age and adjusted for highway fuel use, other highway-related laws, the other GDL components shown in the table, state, and state- and age-specific linear trends, seasonality, and unemployment. In models with adult covariates, the rate ratios are also adjusted for the contemporaneous state- and age-specific driver fatal crash involvement rates of each included adult age group, as specified. GDL = Graduated driver licensing. 95% CI = 95% confidence interval for the adjusted rate ratios. CLR = Confidence limit ratio (ratio of upper and lower confidence limits).
**p* < .05 (reliably estimated). †*p* < .10 (marginally reliably estimated).

19 Year Olds Learner Permit Holding Period Lengths. Compared to time periods when younger teens were not required to hold learner permits for minimum lengths of time, 19-year-old driver fatal crash incidence was not reliably different when younger teens were required to hold learner permits for minimum periods lasting less than 3 months (RR = 0.97, 95% CI = 0.90, 1.05), 3–4 months (RR = 1.02, 95% CI = 0.92, 1.12), 5–6 months (RR = 1.07, 95% CI = 0.96, 1.19), or 9–12 months (RR = 1.07, 95% CI = 0.92, 1.23). The estimates were similar when driver fatal crash involvement rates of adults were not used as covariates and when only those for 40–59 year olds were used.

19 Year Olds Supervised Driving Hours. Relative to time periods when younger teens were not required to complete supervised driving hours, 19-year-old driver fatal crash incidence was reliably 22% *higher* (RR = 1.22, 95% CI = 1.09, 1.37) when younger teens were required drive supervised for 20 or fewer hours. However, 19-year-old driver fatal crash incidence was not different when younger teens were required to drive supervised for 25–35 hours, (RR = 1.02, 95% CI = 0.95, 1.10). Nineteen-year-old driver fatal crash incidence was reliably 14% higher (RR = 1.14, 95% CI = 1.03, 1.26) when younger teens were required to drive supervised for 40 hours and 16% higher (RR = 1.16, 95% CI = 1.04, 1.29) when younger teens were required to drive supervised for 50–60 hours. The estimates were similar when driver fatal crash involvement rates of adults were not used as covariates and when only those for 40–59 year olds were used.

19 Year Olds Intermediate Stage License Ages. Compared to time periods when younger teens were not subject to intermediate licensing stages, 19-year-old driver fatal crash incidence was not reliably different when younger teens were subject to intermediate licensing stages beginning at ages younger than 16 years (RR = 0.87, 95% CI = 0.69, 1.08) or from ages 16 years–16, 5 months (RR = 0.99, 95% CI = 0.82, 1.19). However, 19-year-old driver fatal crash incidence was reliably 27% lower (RR = 0.73, 95% CI = 0.57, 0.93) when younger teens were subject to intermediate licensing stages beginning at ages from 16, 6 months–17 years. The estimates were similar when driver fatal crash involvement rates of adults were not used as covariates and when only those for 40–59 year olds were used.

19 Year Olds Nighttime Driving Restrictions. Relative to time periods when younger teens were not subject to restrictions on the nighttime hours during which they were allowed to drive unsupervised, 19-year-old driver fatal crash incidence was not different when younger teens were subject to nighttime driving restrictions of any start time. Specifically, 19-year-old driver fatal crash incidence was not different when younger teens were subject to nighttime driving restrictions starting at 10:00 pm or earlier (RR = 1.14, 95% CI = 0.97, 1.34), 11:00 pm (RR = 1.08, 95% CI = 0.87, 1.34), 12:00 am (RR = 1.10, 95% CI = 0.89, 1.37), or 1:00 am (RR = 1.16, 95% CI = 0.94, 1.44).

While the nighttime driving restriction estimates for 19 year olds did not differ by 10% or more as a function of whether, and which, adult driver fatal crash involvement rates were used as covariates, there were some differences in the reliability of the estimates. Specifically, when younger teens were subject to nighttime driving restrictions starting at 10:00 pm or earlier, 19-year-old driver fatal crash incidence was reliably higher when driver fatal crash involvement rates of adults were not used as covariates (RR = 1.22, 95% CI =

1.03, 1.46) and also when only those for 40–59 year olds were used (RR = 1.24, 95% CI = 1.05, 1.46). In addition, when only the driver fatal crash involvement rates of 40–59 year olds were used as a covariate, 19-year-old driver fatal crash incidence was higher during time periods when younger teens were subject to nighttime driving restrictions starting at 1:00 am (RR = 1.23, 95% CI = 1.00, 1.51), though the estimate was only marginally reliable.

19 Year Olds Passenger Driving Restrictions. Compared to time periods when younger teens were not restricted with regard to the number of teen passengers they could transport while driving unsupervised, 19-year-old driver fatal crash incidence was not different during periods when younger teens were completely restricted from transporting teen passengers for time periods lasting less than 6 months (RR = 1.06, 95% CI = 0.89, 1.26) or 6 months or longer (RR = 1.01, 95% CI = 0.92, 1.10). Similarly, 19-year-old driver fatal crash incidence was not different when younger teens were prohibited from transporting more than one teen passenger for time periods lasting 6 months or longer (RR = 1.03, 95% CI = 0.94, 1.14) or more than two or three teen passengers for time periods lasting 6 months or longer (RR = 1.00, 95% CI = 0.90, 1.12). Again the estimates were similar when driver fatal crash involvement rates of adults were not used as covariates and when only those for 40–59 year olds were used.

19 Year Olds Unrestricted License Ages. Relative to time periods when younger teens were granted unrestricted licensure at ages beginning from 15 years–15, 11 months, 19-year-old driver fatal crash incidence was reliably lower when unrestricted licensure was granted at any ages from 16–18 years. Specifically, 19-year-old driver fatal crash incidence was reliably

20% lower (RR = 0.80, 95% CI = 0.73, 0.88) when younger teens were granted unrestricted licensure at ages beginning from 16 years–16, 5 months, reliably 35% lower (RR = 0.65, 95% CI = 0.58, 0.73) from 16, 6 months–16, 11 months, reliably 37% lower (RR = 0.63, 95% CI = 0.51, 0.77) from 17 years–17, 5 months, and reliably 35% lower (RR = 0.65, 95% CI = 0.53, 0.79) from 17, 6 months–18 years. The estimates were similar when driver fatal crash involvement rates of adults were not used as covariates and when only those for 40–59 year olds were used.

5. Summary of Individual Age Group GDL Program Core Components Findings (Aim 3) and How Effects Varied as a Function of Methodological Choices (Aim 5)

The results presented in the last four sections addressed whether the seven GDL program core components were associated with changes in driver fatal crash involvement rates for 16, 17, 18, and 19 year olds (separately) and how any effects varied as a function of the specific component calibrations (Aim 3). In addition, comparisons were made between different models to describe how the results varied as a function of whether, and which, adult age group driver fatal crash involvement rates were used as contemporaneous covariates to remove state-specific historical variability from unmeasured factors (Aim 5). The parameter estimates for the GDL program core component calibrations were similar (i.e., they did not differ by 10% or more) in most cases regardless of whether, and which, adult driver fatal crash involvement rates were used as covariates. However, in seven instances the additional adjustments provided by including the driver fatal crash involvement rates of all adult age groups made meaningful differences in the rate ratio estimates. Therefore, for purposes of summarizing the GDL program core component analyses across all teen age groups (ages

16–19 years), the results from the model using all adult age group crash rates as covariates were selected for further discussion. Because the final purpose of these analyses was to describe which GDL program core components should be included in programs and how the individual components might be optimally calibrated by determining which component calibrations were associated with the largest net overall reductions in teen driver fatal crash involvements (16–19 year olds combined), the discussion here is presented by component rather than by age group. To aid in making comparisons, the estimates from the all-adult crash rate covariate model are repeated for all teen age groups in each GDL core component table in the following sections.

Each GDL program core component table also shows the estimated increase or decrease in driver fatal crash involvements attributable to each component calibration. These estimates of attributable driver fatal crash involvements were calculated for each teen age group and for three different time spans: (a) an annual average (based on the last 5 years), (b) a 5-year period (2003–2007), and (c) the entire 12-year period beginning when the first three-stage U.S. GDL program was implemented (1996–2007). These estimates are based on calculating population attributable fractions (for rate ratios ≥ 1) or prevented fractions (for rate ratios < 1), as discussed earlier, and applying them to these selected time periods (Benichou, 2001; Rockhill et al., 1998). For purposes of the calculations, all GDL program core component calibration estimates were used, regardless of their statistical reliability, and it was assumed that the effects were invariant across time. The latter is a strong assumption, so the estimates should be considered to be only approximations of driver fatal crash involvements attributable to each GDL program core component calibration. Also, because crashes can be attributed to multiple GDL program core components, the counts are not independent across component tables.

Summary of Learner Permit Minimum Ages Findings (Aim 3). The specific ages that teens were allowed to begin learning to drive while under the supervision of an adult, usually under the auspices of holding a learner permit, were not associated with reliable changes in the driver fatal crash involvement rates for 16, 17, or 19 year olds, but were associated with changes in incidence for 18 year olds (Table 24). Eighteen-year-old driver fatal crash incidences were lower when younger teens were allowed to begin learner-stage driving (i.e., obtain learner permits) at ages younger than 15 years (the most common age being 14 years) than when they had to wait until some older age, up to 16 years. Specifically, 18-year-old incidences were higher when learner permit minimum ages were from 15 years–15, 5 months (17% higher), from 15, 6 months–15, 11 months (25% higher), or when the minimum age was 16 years (20% higher).

Table 24. Summary of 16–19-Year-Old Adjusted Driver Fatal Crash Involvement Rate Ratios and Age-Specific Driver Fatal Crash Involvements Attributable to each Learner Permit Minimum Age Calibration, United States

Learner permit age (minimum)	Adjusted rate ratio	95% confidence interval	*p*	Confidence limit ratio	1996–2007 population attributable fraction	1996–2007 prevented fraction	Attributable fatal crash involvements: Yearly average[a]	Attributable fatal crash involvements: 2003–2007	Attributable fatal crash involvements: 1996–2007
16 year olds									
< 15 years‡	—								
15 years–15, 5 months	1.12	0.91, 1.38	.2895	1.52	0.0657	-0.0703	53	266	793
15, 6 months–15, 11 months	0.98	0.79, 1.23	.8791	1.56	-0.0031	0.0031	-3	-15	-37
16 years	0.88	0.68, 1.13	.3181	1.66	-0.0133	0.0131	-9	-46	-158
Age group net					0.0493	-0.0541	41	205	597
17 year olds									
< 15 years‡	—								
15 years–15, 5 months	1.06	0.91, 1.22	.4681	1.34	0.0304	-0.0313	36	182	499
15, 6 months–15, 11 months	1.03	0.84, 1.27	.7533	1.52	0.0059	-0.0059	9	45	96
16 years	0.93	0.72, 1.21	.5872	1.68	-0.0114	0.0113	-14	-70	-185
Age group net					0.0248	-0.0260	31	156	410
18 year olds									
< 15 years‡	—								
15 years–15, 5 months	1.17	1.00, 1.36	.0453*	1.36	0.0870	-0.0953	136	681	1,802
15, 6 months–15, 11 months	1.25	1.06, 1.48	.0089*	1.40	0.0358	-0.0371	77	387	742
16 years	1.20	0.98, 1.46	.0743†	1.49	0.0224	-0.0229	37	185	463
Age group net					0.1452	-0.1554	251	1,253	3,007
19 year olds									
< 15 years‡	—								
15 years–15, 5 months	0.97	0.87, 1.08	.5593	1.24	-0.0197	0.0194	-29	-146	-390
15, 6 months–15, 11 months	0.98	0.86, 1.11	.7050	1.29	-0.0046	0.0045	-10	-49	-92
16 years	0.87	0.73, 1.04	.1266	1.42	-0.0200	0.0196	-29	-144	-396
Age group net					-0.0443	0.0435	-68	-338	-878

Note. The adjusted ratio ratios are from a model stratified by age and adjusted for highway fuel use, other highway-related laws, other GDL core components, state, and state- and age-specific linear trends, seasonality, unemployment, and contemporaneous age 20–24, 25–39, 40–59, and 60 or older driver fatal crash involvement rates. Population attributable fraction (PAF_{it}) = $pd_{it} \times [(RR_i - 1) / RR_i]$, where pd_{it} = proportion of fatal involvements occurring under each specific component calibration (i) during the specified time period (t) and RR_i is the adjusted rate ratio (Formula 4 from Rockhill et al., 1998). Prevented fraction (PF_{it}) = $PAF_{it} / (PAF_{it} - 1)$ (derived using Formula 11 from Benichou, 2001). If $RR_i \geq 1$, then attributable fatal crash involvements = PAF_{it} × number of crash involvements$_{it}$, where t = time period specified in each of the last two columns. If $RR_i < 1$, then attributable fatal crash involvements = $-PF_{it}$ × number of involvements$_{it}$.
‡ = referent category. **p* < .05 (reliably estimated). †*p* < .10 (marginally reliably estimated).
[a]Average based on the 5-year period 2003–2007.

Summary of Learner Permit Holding Period Lengths Findings (Aim 3). The minimum lengths of time that young teens were required hold learner permits were reliably associated with changes in the driver fatal crash involvement rates for 16 and 17 year olds, but not those for 18 or 19 year olds (Table 25), relative to not having required learner permit holding periods. The driver fatal crash incidences of 16 and 17 year olds were not different when young teens were required to hold learner permits for minimum lengths of time lasting less than 3 months (the most common length being 1 month) or 3–4 months, relative to not having minimum learner permit holding periods. However, their incidences were marginally 11% lower (16 year olds) and 9% lower (17 year olds) when young teens were required to hold learner permits for 5–6 months. Their incidences were also 26% lower (16 year olds) and 17% lower (17 year olds) when young teens were required to hold learner permits for even longer 9–12 month time periods. None of the learner permit holding period lengths were associated with different 18 or 19 year old incidences.

Table 25. Summary of 16–19-Year-Old Adjusted Driver Fatal Crash Involvement Rate Ratios and Age-Specific Driver Fatal Crash Involvements Attributable to each Learner Permit Holding Period Length Calibration, United States

Learner permit holding period	Adjusted rate ratio	95% confidence interval	*p*	Confidence limit ratio	1996–2007 population attributable fraction	1996–2007 prevented fraction	Attributable fatal crash involvements		
							Yearly average[a]	2003–2007	1996–2007
16 year olds									
None‡	—								
< 3 months	1.05	0.91, 1.20	.5355	1.33	0.0044	-0.0045	1	7	54
3–4 months	1.00	0.89, 1.13	.9868	1.27	0.0001	-0.0001	0	0	1
5–6 months	0.89	0.78, 1.01	.0659†	1.28	-0.0518	0.0493	-62	-310	-595
9–12 months	0.74	0.62, 0.89	.0010*	1.43	-0.0398	0.0382	-51	-255	-462
Age group net					-0.0871	0.0830	-112	-558	-1,002
17 year olds									
None‡	—								
< 3 months	0.95	0.85, 1.05	.3170	1.23	-0.0049	0.0048	-2	-9	-80
3–4 months	0.99	0.91, 1.08	.8022	1.19	-0.0010	0.0010	-1	-5	-16
5–6 months	0.91	0.83, 1.01	.0869†	1.23	-0.0427	0.0410	-76	-382	-673
9–12 months	0.83	0.70, 0.97	.0234*	1.39	-0.0246	0.0240	-47	-234	-395
Age group net					-0.0732	0.0708	-126	-630	-1,164
18 year olds									
None‡	—								
< 3 months	1.01	0.93, 1.10	.7302	1.18	0.0012	-0.0012	1	3	25
3–4 months	0.99	0.86, 1.13	.8680	1.32	-0.0009	0.0009	-1	-7	-20
5–6 months	1.03	0.92, 1.15	.6573	1.25	0.0118	-0.0119	29	143	244
9–12 months	0.85	0.70, 1.03	.1028	1.47	-0.0215	0.0210	-53	-265	-435
Age group net					-0.0094	0.0088	-25	-125	-186
19 year olds									
None‡	—								
< 3 months	0.97	0.90, 1.05	.4994	1.17	-0.0022	0.0022	-1	-5	-45
3–4 months	1.02	0.92, 1.12	.7514	1.21	0.0012	-0.0012	2	9	25
5–6 months	1.07	0.96, 1.19	.2154	1.24	0.0311	-0.0321	73	366	627
9–12 months	1.07	0.92, 1.23	.3753	1.33	0.0078	-0.0078	19	96	157
Age group net					0.0379	-0.0390	93	466	764

Note. The adjusted ratio ratios are from a model stratified by age and adjusted for highway fuel use, other highway-related laws, other GDL core components, state, and state- and age-specific linear trends, seasonality, unemployment, and contemporaneous age 20–24, 25–39, 40–59, and 60 or older driver fatal crash involvement rates. Population attributable fraction (PAF_{it}) = $pd_{it} \times [(RR_i - 1) / RR_i]$, where pd_{it} = proportion of fatal involvements occurring under each specific component calibration (*i*) during the specified time period (*t*) and RR_i is the adjusted rate ratio (Formula 4 from Rockhill et al., 1998). Prevented fraction (PF_{it}) = $PAF_{it} / (PAF_{it} - 1)$ (derived using Formula 11 from Benichou, 2001). If $RR_i \geq 1$, then attributable fatal crash involvements = PAF_{it} × number of crash involvements$_{it}$, where *t* = time period specified in each of the last two columns. If $RR_i < 1$, then attributable fatal crash involvements = $-PF_{it}$ × number of involvements$_{it}$.
‡ = referent category. *$p < .05$ (reliably estimated). †$p < .10$ (marginally reliably estimated).
[a]Average based on the 5-year period 2003–2007.

Summary of Supervised Driving Hours Findings (Aim 3). The numbers of hours that young teens were required to drive with a supervising adult were reliably associated with changes in the driver fatal crash involvement rates for every teen age group (Table 26), relative to not requiring young teens to complete supervised driving hours. However, the rate ratios were almost all in an unexpected direction—towards higher crash incidences. When younger teens were required to complete 20 or fewer hours of supervised driving (the most common requirement being 20 hours) 19-year-old incidence was 22% higher, though the incidences for the other teen age groups were not different. Incidences were not different for any of the teen age groups when young teens were required to complete 25–35 hours of supervised driving. However, incidences were 14% higher (16 year olds), 13% higher (17 year olds), not different (18 year olds), and 14% higher (19 year olds) when young teens were required to complete 40 hours of supervised driving. Finally, 16 and 17 year old incidences were not different, but those for older teens were 20% higher (18 year olds) and 16% higher (19 year olds) when young teens were required to complete 50–60 hours of supervised driving.

Table 26. Summary of 16–19-Year-Old Adjusted Driver Fatal Crash Involvement Rate Ratios and Age-Specific Driver Fatal Crash Involvements Attributable to each Supervised Driving Hours Calibration, United States

Supervised driving hours (total)	Adjusted rate ratio	95% confidence interval	*p*	Confidence limit ratio	1996–2007 population attributable fraction	1996–2007 prevented fraction	Attributable fatal crash involvements		
							Yearly average[a]	2003–2007	1996–2007
16 year olds									
None required‡	—								
≤ 20 hours	1.03	0.87, 1.21	.7570	1.39	0.0012	-0.0012	2	10	14
25–35 hours	0.95	0.85, 1.06	.3694	1.25	-0.0042	0.0042	-5	-24	-50
40 hours	1.14	1.01, 1.29	.0415*	1.29	0.0070	-0.0071	12	58	85
50–60 hours	1.02	0.92, 1.13	.6975	1.23	0.0046	-0.0046	6	31	55
Age group net					0.0086	-0.0087	15	74	104
17 year olds									
None required‡	—								
≤ 20 hours	1.04	0.94, 1.15	.4243	1.22	0.0022	-0.0022	5	27	36
25–35 hours	1.06	0.90, 1.26	.4702	1.41	0.0041	-0.0042	7	33	68
40 hours	1.13	1.02, 1.25	.0155*	1.22	0.0068	-0.0069	16	80	112
50–60 hours	1.05	0.94, 1.17	.3863	1.24	0.0119	-0.0120	23	116	195
Age group net					0.0250	-0.0253	51	256	411
18 year olds									
None required‡	—								
≤ 20 hours	1.04	0.89, 1.21	.6480	1.36	0.0019	-0.0019	6	30	40
25–35 hours	1.03	0.94, 1.13	.5352	1.20	0.0019	-0.0019	4	20	39
40 hours	0.90	0.78, 1.05	.1877	1.35	-0.0055	0.0055	-16	-81	-113
50–60 hours	1.20	1.06, 1.37	.0049*	1.29	0.0471	-0.0494	116	580	975
Age group net					0.0454	-0.0478	110	548	941
19 year olds									
None required‡	—								
≤ 20 hours	1.22	1.09, 1.37	.0006*	1.25	0.0092	-0.0093	28	138	185
25–35 hours	1.02	0.95, 1.10	.5179	1.16	0.0016	-0.0016	3	16	32
40 hours	1.14	1.03, 1.26	.0132*	1.23	0.0067	-0.0068	19	97	136
50–60 hours	1.16	1.04, 1.29	.0060*	1.23	0.0376	-0.0390	89	446	757
Age group net					0.0551	-0.0567	139	697	1,110

Note. The adjusted ratio ratios are from a model stratified by age and adjusted for highway fuel use, other highway-related laws, other GDL core components, state, and state- and age-specific linear trends, seasonality, unemployment, and contemporaneous age 20–24, 25–39, 40–59, and 60 or older driver fatal crash involvement rates. Population attributable fraction (PAF_{it}) = $pd_{it} \times [(RR_i - 1) / RR_i]$, where pd_{it} = proportion of fatal involvements occurring under each specific component calibration (*i*) during the specified time period (*t*) and RR_i is the adjusted rate ratio (Formula 4 from Rockhill et al., 1998). Prevented fraction (PF_{it}) = $PAF_{it} / (PAF_{it} - 1)$ (derived using Formula 11 from Benichou, 2001). If $RR_i \geq 1$, then attributable fatal crash involvements = PAF_{it} × number of crash involvements$_{it}$, where *t* = time period specified in each of the last two columns. If $RR_i < 1$, then attributable fatal crash involvements = $-PF_{it}$ × number of involvements$_{it}$.

‡ = referent category. **p* < .05 (reliably estimated). †*p* < .10 (marginally reliably estimated).

[a]Average based on the 5-year period 2003–2007.

Summary of Intermediate Stage License Ages Findings (Aim 3). The ages that young teens were allowed to begin unsupervised, but initially restricted driving as part of intermediate licensing stages were reliably associated with changes in the driver fatal crash involvement rates for 16, 18, and 19 year olds, but not those for 17 year olds (Table 27), relative to not having intermediate licensing stages. The driver fatal crash incidence of 16 year olds was 29% higher when young teens were subject to intermediate licensing stages beginning at ages younger than 16 years (the most common age being 15 years), but the incidences for the other teen age groups were not different. When young teens were subject to intermediate licensing stages beginning at ages from 16 years–16, 5 months, 16-year-old incidence was marginally 18% higher and 18-year-old incidence was 33% higher, but incidences were not different for 17 or 19 year olds. When young teens were subject to intermediate licensing stages beginning at ages from 16, 6 months–17 years, incidences were 23% lower (16 year olds), not different (17 year olds), marginally 26% higher (18 year olds), and 27% lower (19 year olds).

Table 27. Summary of 16–19-Year-Old Adjusted Driver Fatal Crash Involvement Rate Ratios and Age-Specific Driver Fatal Crash Involvements Attributable to each Intermediate Stage License Age Calibration, United States

Intermediate stage license age (minimum)	Adjusted rate ratio	95% confidence interval	*p*	Confidence limit ratio	1996–2007 population attributable fraction	1996–2007 prevented fraction	Attributable fatal crash involvements: Yearly average[a]	Attributable fatal crash involvements: 2003–2007	Attributable fatal crash involvements: 1996–2007
16 year olds									
No intermediate license stage‡	—								
< 16 years	1.29	1.08, 1.55	.0058*	1.44	0.0132	-0.0133	13	66	159
16 years–16, 5 months	1.18	0.99, 1.41	.0653†	1.43	0.0806	-0.0877	97	484	973
16, 6 months–17 years	0.77	0.62, 0.96	.0197*	1.56	-0.0096	0.0095	-13	-67	-115
Age group net					0.0841	-0.0915	96	482	1,016
17 year olds									
No intermediate license stage‡	—								
< 16 years	0.92	0.70, 1.21	.5682	1.73	-0.0048	0.0047	-7	-36	-78
16 years–16, 5 months	0.99	0.72, 1.37	.9715	1.90	-0.0031	0.0031	-5	-26	-51
16, 6 months–17 years	1.03	0.75, 1.42	.8369	1.88	0.0021	-0.0021	5	24	35
Age group net					-0.0058	0.0057	-8	-38	-94
18 year olds									
No intermediate license stage‡	—								
< 16 years	1.08	0.81, 1.44	.5971	1.77	0.0041	-0.0041	8	38	85
16 years–16, 5 months	1.33	1.06, 1.67	.0149*	1.58	0.1381	-0.1603	305	1,527	2,860
16, 6 months–17 years	1.26	0.99, 1.62	.0631†	1.64	0.0130	-0.0131	36	180	268
Age group net					0.1552	-0.1775	349	1,745	3,213
19 year olds									
No intermediate license stage‡	—								
< 16 years	0.87	0.69, 1.08	.2066	1.56	-0.0089	0.0088	-18	-88	-177
16 years–16, 5 months	0.99	0.82, 1.19	.9099	1.45	-0.0060	0.0060	-13	-63	-120
16, 6 months–17 years	0.73	0.57, 0.93	.0117*	1.64	-0.0217	0.0212	-55	-275	-428
Age group net					-0.0365	0.0360	-85	-426	-725

Note. The adjusted ratio ratios are from a model stratified by age and adjusted for highway fuel use, other highway-related laws, other GDL core components, state, and state- and age-specific linear trends, seasonality, unemployment, and contemporaneous age 20–24, 25–39, 40–59, and 60 or older driver fatal crash involvement rates. Population attributable fraction (PAF_{it}) = $pd_{it} \times [(RR_i - 1) / RR_i]$, where pd_{it} = proportion of fatal involvements occurring under each specific component calibration (i) during the specified time period (t) and RR_i is the adjusted rate ratio (Formula 4 from Rockhill et al., 1998). Prevented fraction (PF_{it}) = $PAF_{it} / (PAF_{it} - 1)$ (derived using Formula 11 from Benichou, 2001). If $RR_i \geq 1$, then attributable fatal crash involvements = PAF_{it} × number of crash involvements$_{it}$, where t = time period specified in each of the last two columns. If $RR_i < 1$, then attributable fatal crash involvements = -PF_{it} × number of involvements$_{it}$.
‡ = referent category. *$p < .05$ (reliably estimated). †$p < .10$ (marginally reliably estimated).
[a]Average based on the 5-year period 2003–2007.

Summary of Nighttime Driving Restrictions Findings (Aim 3). Restrictions on the nighttime hours during which young teens were allowed to drive unsupervised were associated with reliable changes in the driver fatal crash involvement rates for 16 year olds and marginally reliable changes in those for 18 year olds, but were not associated with changes in the rates for 17 or 19 year olds (Table 28), relative to not restricting the nighttime hours during which young teens were allowed to drive unsupervised. When young teens were subject to nighttime driving restrictions starting at 10:00 pm or earlier (the most common start time being 9:00 pm), 16-year-old driver fatal crash incidence was 19% lower, but the incidences for the other teen age groups were not different. The incidences for 16, 17, and 19 year olds were not different when young teens were restricted from driving unsupervised after 11:00 pm, but the incidence for 18 year olds was marginally 25% lower. Incidences were not different for any of the teen age groups when young teens were restricted from driving unsupervised after 12:00 am. However, 18-year-old incidence was marginally 20% lower when young teens were restricted from driving unsupervised after 1:00 am.

Table 28. Summary of 16–19-Year-Old Adjusted Driver Fatal Crash Involvement Rate Ratios and Age-Specific Driver Fatal Crash Involvements Attributable to each Nighttime Driving Restriction Calibration, United States

Nighttime driving restriction (start)	Adjusted rate ratio	95% confidence interval	*p*	Confidence limit ratio	1996–2007 population attributable fraction	1996–2007 prevented fraction	Attributable fatal crash involvements		
							Yearly average[a]	2003–2007	1996–2007
16 year olds									
None‡	—								
≤ 10:00 pm	0.81	0.69, 0.95	.0097*	1.38	-0.0186	0.0183	-21	-105	-221
11:00 pm	0.96	0.76, 1.21	.7261	1.58	-0.0048	0.0047	-6	-30	-57
12:00 am	1.04	0.84, 1.28	.7222	1.52	0.0112	-0.0113	14	69	135
1:00 am	0.91	0.75, 1.11	.3594	1.49	-0.0095	0.0094	-11	-53	-114
Age group net					-0.0217	0.0211	-24	-120	-256
17 year olds									
None‡	—								
≤ 10:00 pm	0.97	0.75, 1.26	.8189	1.69	-0.0031	0.0031	-5	-24	-50
11:00 pm	0.99	0.69, 1.42	.9418	2.06	-0.0019	0.0019	-4	-18	-31
12:00 am	1.02	0.72, 1.44	.9283	2.01	0.0049	-0.0049	9	43	80
1:00 am	0.94	0.66, 1.33	.7219	2.02	-0.0057	0.0057	-9	-44	-94
Age group net					-0.0058	0.0058	-9	-43	-95
18 year olds									
None‡	—								
≤ 10:00 pm	0.97	0.80, 1.18	.7831	1.47	-0.0026	0.0026	-5	-26	-53
11:00 pm	0.75	0.53, 1.05	.0919†	1.96	-0.0515	0.0490	-119	-595	-1,015
12:00 am	0.81	0.60, 1.11	.1962	1.86	-0.0737	0.0687	-152	-761	-1,422
1:00 am	0.80	0.61, 1.04	.0977†	1.71	-0.0219	0.0215	-43	-217	-444
Age group net					-0.1498	0.1417	-320	-1,600	-2,934
19 year olds									
None‡	—								
≤ 10:00 pm	1.14	0.97, 1.34	.1077	1.38	0.0126	-0.0127	26	129	253
11:00 pm	1.08	0.87, 1.34	.4885	1.53	0.0111	-0.0112	27	133	223
12:00 am	1.10	0.89, 1.37	.3656	1.54	0.0300	-0.0310	65	327	606
1:00 am	1.16	0.94, 1.44	.1579	1.52	0.0116	-0.0117	22	109	233
Age group net					0.0652	-0.0666	140	698	1,315

Note. The adjusted ratio ratios are from a model stratified by age and adjusted for highway fuel use, other highway-related laws, other GDL core components, state, and state- and age-specific linear trends, seasonality, unemployment, and contemporaneous age 20–24, 25–39, 40–59, and 60 or older driver fatal crash involvement rates. Population attributable fraction (PAF_{it}) = $pd_{it} \times [(RR_i - 1) / RR_i]$, where pd_{it} = proportion of fatal involvements occurring under each specific component calibration (i) during the specified time period (t) and RR_i is the adjusted rate ratio (Formula 4 from Rockhill et al., 1998). Prevented fraction (PF_{it}) = $PAF_{it} / (PAF_{it} - 1)$ (derived using Formula 11 from Benichou, 2001). If $RR_i \geq 1$, then attributable fatal crash involvements = PAF_{it} × number of crash involvements$_{it}$, where t = time period specified in each of the last two columns. If $RR_i < 1$, then attributable fatal crash involvements = $-PF_{it}$ × number of involvements$_{it}$.

‡ = referent category. *$p < .05$ (reliably estimated). †$p < .10$ (marginally reliably estimated).

[a]Average based on the 5-year period 2003–2007.

Summary of Passenger Driving Restrictions Findings (Aim 3). Restrictions on the numbers of teen passengers that young teens were allowed to transport while driving unsupervised were associated with reliable changes in the driver fatal crash involvement rates for 16 and 17 year olds, but not those for 18 or 19 year olds (Table 29), relative to not restricting the numbers of teen passengers young teens could transport while driving unsupervised. Specifically, incidence was 20% lower (16 year olds) and 12% lower (17 year olds) when young teens were restricted from transporting more than one teen passenger for time periods of 6 months or longer (the most common time period being 6 months, though 12 months was also common). However, incidences were not different for any of the teen age groups under the various other passenger restriction calibrations (e.g., completely restricting young teens from transporting any teen passengers while driving unsupervised).

Table 29. Summary of 16–19-Year-Old Adjusted Driver Fatal Crash Involvement Rate Ratios and Age-Specific Driver Fatal Crash Involvements Attributable to each Passenger Driving Restriction Calibration, United States

Passenger driving restriction	Adjusted rate ratio	95% confidence interval	*p*	Confidence limit ratio	1996–2007 population attributable fraction	1996–2007 prevented fraction	Attributable fatal crash involvements		
							Yearly average[a]	2003–2007	1996–2007
16 year olds									
No passenger restriction‡	—								
0 passengers, < 6 months	1.02	0.91, 1.15	.7256	1.26	0.0006	-0.0006	1	4	8
0 passengers, ≥ 6 months	0.91	0.76, 1.09	.2911	1.43	-0.0093	0.0093	-14	-68	-112
1 passenger, ≥ 6 months	0.80	0.72, 0.89	<.0001*	1.24	-0.0296	0.0287	-54	-269	-346
2–3 passengers, ≥ 6 months	0.98	0.87, 1.11	.7952	1.27	-0.0008	0.0008	-1	-5	-10
Age group net					-0.0391	0.0381	-68	-338	-460
17 year olds									
No passenger restriction‡	—								
0 passengers, < 6 months	1.10	0.89, 1.36	.3761	1.53	0.0027	-0.0027	5	26	44
0 passengers, ≥ 6 months	0.98	0.85, 1.13	.7950	1.32	-0.0021	0.0021	-4	-21	-34
1 passenger, ≥ 6 months	0.88	0.78, 1.00	.0465*	1.28	-0.0171	0.0168	-44	-219	-277
2–3 passengers, ≥ 6 months	1.03	0.93, 1.14	.5172	1.22	0.0020	-0.0020	4	20	32
Age group net					-0.0146	0.0142	-39	-194	-234
18 year olds									
No passenger restriction‡	—								
0 passengers, < 6 months	0.87	0.73, 1.04	.1254	1.43	-0.0040	0.0040	-10	-50	-83
0 passengers, ≥ 6 months	1.00	0.85, 1.17	.9805	1.38	-0.0003	0.0003	-1	-3	-6
1 passenger, ≥ 6 months	0.99	0.84, 1.18	.9426	1.40	-0.0009	0.0008	-3	-14	-18
2–3 passengers, ≥ 6 months	0.98	0.87, 1.10	.7076	1.26	-0.0013	0.0013	-3	-15	-27
Age group net					-0.0064	0.0064	-17	-83	-133
19 year olds									
No passenger restriction‡	—								
0 passengers, < 6 months	1.06	0.89, 1.26	.5357	1.42	0.0014	-0.0014	4	18	28
0 passengers, ≥ 6 months	1.01	0.92, 1.10	.9117	1.19	0.0007	-0.0007	2	8	13
1 passenger, ≥ 6 months	1.03	0.94, 1.14	.5052	1.22	0.0044	-0.0045	15	73	90
2–3 passengers, ≥ 6 months	1.00	0.90, 1.12	.9736	1.24	0.0001	-0.0001	0	1	2
Age group net					0.0066	-0.0066	20	100	133

Note. The adjusted ratio ratios are from a model stratified by age and adjusted for highway fuel use, other highway-related laws, other GDL core components, state, and state- and age-specific linear trends, seasonality, unemployment, and contemporaneous age 20–24, 25–39, 40–59, and 60 or older driver fatal crash involvement rates. Population attributable fraction (PAF_{it}) = $pd_{it} \times [(RR_i - 1) / RR_i]$, where pd_{it} = proportion of fatal involvements occurring under each specific component calibration (i) during the specified time period (t) and RR_i is the adjusted rate ratio (Formula 4 from Rockhill et al., 1998). Prevented fraction (PF_{it}) = $PAF_{it} / (PAF_{it} - 1)$ (derived using Formula 11 from Benichou, 2001). If $RR_i \geq 1$, then attributable fatal crash involvements = $PAF_{it} \times$ number of crash involvements$_{it}$, where t = time period specified in each of the last two columns. If $RR_i < 1$, then attributable fatal crash involvements = $-PF_{it} \times$ number of involvements$_{it}$.

‡ = referent category. *$p < .05$ (reliably estimated). †$p < .10$ (marginally reliably estimated).

[a]Average based on the 5-year period 2003–2007.

Summary of Unrestricted License Ages Findings (Aim 3). The ages that teens were granted unrestricted licensure were associated with reliable changes in the driver fatal crash involvement rates for 16, 17, and 19 year olds, but not those for 18 year olds (Table 30), relative to granting unrestricted licensure at ages beginning from 15 years–15, 11 months (the most common age being 15 years). The adjusted rate ratios for unrestricted license ages were all directionally consistent within each teen age group, suggesting that granting unrestricted licensure starting from age 16 was directionally consistent with lower driver fatal crash incidences for 16 and 19 year olds, but higher incidence for 17 year olds. While not all of the adjusted rate ratios were statistically reliable, the general patterns seem fairly evident.

Driver fatal crash incidence was 25% higher for 17 year olds and 20% lower for 19 year olds, but not different for 16 or 18 year olds, when unrestricted licensure was granted at ages beginning from 16 years–16, 5 months. Incidences were 22% lower (16 year olds), 53% higher (17 year olds), not different (18 year olds), and 35% lower (19 year olds) when unrestricted licensure was granted at ages beginning from 16, 6 months–16, 11 months. When unrestricted licensure was granted at ages beginning from 17 years–17, 5 months, 16-year-old incidence was 26% lower, 17- and 18-year-old incidences were not different, and 19-year-old incidence was 37% lower. Finally, when unrestricted licensure was granted at ages beginning from 17, 6 months–18 years, incidences were 22% lower (16 year olds), 33% higher (17 year olds), not different (18 year olds), and 35% lower (19 year olds).

Table 30. Summary of 16–19-Year-Old Adjusted Driver Fatal Crash Involvement Rate Ratios and Age-Specific Driver Fatal Crash Involvements Attributable to each Unrestricted License Age Calibration, United States

Unrestricted license age	Adjusted rate ratio	95% confidence interval	*p*	Confidence limit ratio	1996–2007 population attributable fraction	1996–2007 prevented fraction	Attributable fatal crash involvements: Yearly average[a]	Attributable fatal crash involvements: 2003–2007	Attributable fatal crash involvements: 1996–2007
16 year olds									
15 years–15, 11 months‡	—								
16 years–16, 5 months	0.89	0.78, 1.02	.1072	1.31	-0.0464	0.0443	-14	-68	-535
16, 6 months–16, 11 months	0.78	0.66, 0.93	.0045*	1.40	-0.0334	0.0323	-48	-238	-390
17 years–17, 5 months	0.74	0.56, 0.97	.0293*	1.72	-0.1003	0.0911	-95	-477	-1,100
17, 6 months–18 years	0.78	0.61, 1.00	.0473*	1.63	-0.0538	0.0511	-59	-293	-616
Age group net					-0.2339	0.2188	-215	-1,076	-2,641
17 year olds									
15 years–15, 11 months‡	—								
16 years–16, 5 months	1.25	1.07, 1.46	.0043*	1.36	0.0682	-0.0732	31	154	1,121
16, 6 months–16, 11 months	1.53	1.24, 1.89	<.0001*	1.53	0.0452	-0.0473	93	463	742
17 years–17, 5 months	1.25	0.95, 1.63	.1075	1.71	0.0603	-0.0642	92	458	991
17, 6 months–18 years	1.33	1.02, 1.75	.0370*	1.72	0.0549	-0.0581	96	478	901
Age group net					0.2286	-0.2428	311	1,553	3,755
18 year olds									
15 years–15, 11 months‡	—								
16 years–16, 5 months	0.92	0.81, 1.04	.1824	1.29	-0.0294	0.0286	-18	-88	-592
16, 6 months–16, 11 months	0.87	0.70, 1.07	.1897	1.53	-0.0198	0.0194	-53	-267	-401
17 years–17, 5 months	0.88	0.66, 1.18	.4030	1.79	-0.0424	0.0407	-81	-404	-843
17, 6 months–18 years	0.94	0.71, 1.23	.6437	1.72	-0.0145	0.0142	-31	-157	-295
Age group net					-0.1060	0.1029	-183	-916	-2,130
19 year olds									
15 years–15, 11 months‡	—								
16 years–16, 5 months	0.80	0.73, 0.88	<.0001*	1.21	-0.0800	0.0741	-49	-246	-1,494
16, 6 months–16, 11 months	0.65	0.58, 0.73	<.0001*	1.27	-0.0712	0.0664	-171	-856	-1,340
17 years–17, 5 months	0.63	0.51, 0.77	<.0001*	1.49	-0.1898	0.1595	-292	-1,460	-3,217
17, 6 months–18 years	0.65	0.53, 0.79	<.0001*	1.49	-0.1158	0.1038	-216	-1,078	-2,093
Age group net					-0.4568	0.4038	-728	-3,640	-8,143

Note. The adjusted ratio ratios are from a model stratified by age and adjusted for highway fuel use, other highway-related laws, other GDL core components, state, and state- and age-specific linear trends, seasonality, unemployment, and contemporaneous age 20–24, 25–39, 40–59, and 60 or older driver fatal crash involvement rates. Population attributable fraction (PAF_{it}) = $pd_{it} \times [(RR_i - 1) / RR_i]$, where pd_{it} = proportion of fatal involvements occurring under each specific component calibration (i) during the specified time period (t) and RR_i is the adjusted rate ratio (Formula 4 from Rockhill et al., 1998). Prevented fraction (PF_{it}) = $PAF_{it} / (PAF_{it} - 1)$ (derived using Formula 11 from Benichou, 2001). If $RR_i \geq 1$, then attributable fatal crash involvements = PAF_{it} × number of crash involvements$_{it}$, where t = time period specified in each of the last two columns. If $RR_i < 1$, then attributable fatal crash involvements = -PF_{it} × number of involvements$_{it}$.

‡ = referent category. *$p < .05$ (reliably estimated). †$p < .10$ (marginally reliably estimated).

[a]Average based on the 5-year period 2003–2007.

Supplementary GDL Core Components Analyses. There was some concern about the possible existence of multicollinearity in the GDL program core components analysis. Specifically, there was concern that the calibrations of some of the GDL components were completely predictable from combinations of other components. The two GDL components that seemed the most likely to be multicollinear with other components were intermediate stage license age and unrestricted license age. The calibrations for these components are, in some states, predictable from other program components, and there was concern that including them in the model along with all the other components could lead to estimation problems. For example, in some states the intermediate stage license age (e.g., age 16 years) is determined by the minimum age that teens are allowed to obtain a learner permit (e.g., 15, 6 months) and the length of the learner permit minimum holding period (e.g., 6 months). Similarly, in other states the unrestricted license age (e.g., age 17 years) is determined by the intermediate stage license age (e.g., age 16 years) and the length of the nighttime and passenger restrictions (e.g., 12 months). There are, however, instances in almost every state during the study time period when the relations among these components were not additive in this fashion.

If multicollinearity was present in the analysis, it could have caused problems with the estimation algorithm, which would cast doubt on the reliability and validity of the resulting parameter estimates. In addition, it was thought that it might explain the surprising and counterintuitive findings for hours of supervised driving practice. To explore the degree to which multicollinearity might have affected the results, the final GDL program core component model with all adult crash rate covariates was replicated under three conditions:

(a) excluding the intermediate stage license age component; (b) excluding both the intermediate stage license age and unrestricted license age components; and (c) excluding all three age-based components (i.e., learner permit minimum age, intermediate stage license age, and unrestricted license age). The adjusted rate ratios resulting from these reduced models were compared to those from the full model that included all seven GDL program core components and those that differed by 10% or more were considered to be meaningfully different (Table 35 in Appendix A).

Across all three reduced models used to explore for multicollinearity, none of the adjusted rate ratios for the supervised driving hours calibrations differed by 10% or more from the full model that included all seven GDL core components. When the intermediate license age component alone was excluded from the analysis, only 13 (14%) of the 92 component calibration rate ratios differed by 10% or more from those in the full model. Of these, six were for nighttime restriction calibrations for 18 and 19 year olds, and two were for nighttime restrictions calibrations for 16 year olds. Only one of the component calibration rate ratios for 17 year olds differed by 10% or more across all three reduced models. The only noteworthy differences across models for 16 year olds were weakening of the effects for two of the unrestricted license age calibrations. The findings were similar when both the intermediate stage license age and unrestricted license age components were excluded, and also when all three age-based components were excluded from the models. Overall, the results of the comparisons across models excluding age-based GDL components did not suggest that multicollinearity was a serious problem in the analysis, nor did they suggest that multicollinearity could explain the counterintuitive findings in regard to hours of supervised driving practice.

One additional follow-up analysis was conducted in an attempt to make sense of the surprising findings for supervised driving hours, and also to explore whether any of the other unexpected findings (e.g., that older unrestricted license ages were strongly associated with lower incidence for 19 year olds) might be due to some type of uncontrolled bias (such as residual historical trends in driver fatal crash involvement rates) or due to an artifact of the coding method or statistical model. Specifically, the GDL program core components analysis was replicated using the driver fatal crash involvement rates of 40–59 year old drivers as the outcome (Table 36 in Appendix A). The logic behind this analysis was to see whether the quarters coded for different supervised driving hours calibrations (and other components) were just really deviant for some unknown reason, such that the increased driver fatal cash incidence found for some teen age groups would be evident among this group of older drivers as well. The analysis was the same as that used for the teens, except that 40–59-year-old driver fatal crash involvement rates were analyzed, and only the remaining adult age groups were used as crash rate covariates to adjust for unmeasured historical factors.

The only statistically reliable rate ratio for a supervised driving hours calibration resulting from the analysis of 40–59-year-old driver fatal crash involvement rates indicated that when young teens were required to complete 25–35 hours of supervised driving practice, the driver fatal crash incidence of 40–59 year olds was marginally 4% higher (RR = 1.04, 95% CI = 1.00, 1.07). Interestingly, this was the only supervised driving hours calibration that was not associated with a change in incidence for at least one teen age group. None of the other supervised driving hours calibrations were reliably associated with changes in 40–59-year-old incidence. In fact, the only other statistically reliable findings at all from the analysis indicated that 40–59-year-old incidence was 4% lower (RR = 0.96, 95% CI = 0.92, 1.00) when young teens were required to hold learner permits for 3–4 months and 7% higher (RR = 1.07, 95% CI = 1.00, 1.13) when unrestricted licensure was granted at ages beginning from 16, 6 months–16, 11 months. Overall, the results of replicating the GDL program core components analysis on 40–59 year olds did not support the hypothesis that the peculiar supervised driving hours results were simply due to some strange pattern in general among the quarters involved in these effects, nor did they suggest that any of the other unexpected findings were due to an artifact of the coding method or statistical model.

6. GDL Program Core Components Findings across All Teen Drivers 16–19 (Aim 4)

Recall that the final purpose of the GDL program core components analysis was to determine which GDL components should be included in programs and how the individual components might be optimally calibrated by determining which component calibrations were associated with the largest net overall reductions in teen driver fatal crash involvements (16–19 year olds combined; Aim 4). Given that the findings indicate that some component calibrations were associated with lower incidence for some teens, but higher incidence for others, it is not yet clear which calibrations are associated with net decreases in overall teen driver fatal crash incidence, nor which calibration for each component is associated with the largest net overall decrease. To address these questions, the estimated increases or decreases in age-specific driver fatal crash involvements attributable to each GDL core component calibration shown in the prior tables were summed across all the teen age groups and are shown in Table 31. The summation was calculated for three different time spans: (a) an annual average (based on the last 5 years), (b) a 5-year period (2003–2007), and (c) the entire 12-year period beginning when the first three-stage U.S. GDL program was implemented (1996–2007). These sums represent the estimated increase or decrease in fatal crash involvements across all teen drivers (ages 16–19) attributable to each component calibration. It is worth mentioning again that these estimates are not independent across components since crashes can be caused or avoided by multiple factors. Also shown in the table for each calibration are rankings in terms of net crash reduction (based on the 1996–2007 time period) within each component and also across all components. These rankings can be used to determine the calibration for each component that was associated with the largest net reduction in teen driver fatal crash involvements (or the smallest net increase), and which component calibrations are associated with the largest net reductions across all components.

At least one calibration for each GDL program core component, except supervised driving hours, was associated with a net decrease in 16–19-year-old (combined) driver fatal crash involvements. The lowest-ranked calibration within each component identifies the optimal calibration associated with the largest net crash reduction across all teen age groups from 1996–2007 for that component. Again the exception is supervised driving hours, for which the best calibration would be the referent category, which was to have no minimum required number of supervised driving hours. The optimal calibration for each component associated with the largest net reduction in teen driver fatal crash involvements is boldfaced in the table.

Table 31. Net 16–19-year-old Driver Fatal Crash Involvements Attributable to each GDL Program Core Component Calibration by Age and Time Span, United States

GDL core component	Attributable fatal crash involvements			1996–2007 rank within component	1996–2007 overall rank
	Yearly average[a]	2003–2007	1996–2007		
Learner permit age (minimum)					
< 15 years‡					
15 years–15, 5 months	197	983	2,704	3	25
15, 6 months–15, 11 months	74	368	709	2	23
16 years	-15	-75	-276	1	11
Learner permit holding period					
None‡					
< 3 months	-1	-5	-46	3	15
3–4 months	-1	-3	-9	4	17
5–6 months	-36	-182	-397	2	10
9–12 months	-132	-658	-1,135	1	5
Supervised driving hours (total)					
None required‡ [b]					
≤ 20 hours	41	204	275	3	22
25–35 hours	9	44	89	1	20
40 hours	31	154	220	2	21
50–60 hours	235	1,173	1,983	4	24
Intermediate stage license age					
No intermediate license stage‡					
< 16 years	-4	-20	-11	2	16
16 years–16, 5 months	384	1,922	3,662	3	26
16, 6 months–17 years	-28	-138	-239	1	12
Nighttime driving restriction					
No nighttime driving restriction‡					
≤ 10:00 pm	-5	-27	-71	4	14
11:00 pm	-102	-509	-880	1	6
12:00 am	-65	-323	-601	2	7
1:00 am	-41	-206	-419	3	9
Passenger driving restriction					
No passenger restriction‡					
0 passengers, < 6 months	0	-1	-4	3	18
0 passengers, ≥ 6 months	-17	-85	-138	2	13
1 passenger, ≥ 6 months	-86	-430	-551	1	8
2–3 passengers, ≥ 6 months	0	1	-2	4	19
Unrestricted license age					
15 years–15, 11 months‡					
16 years–16, 5 months	-50	-249	-1,500	3	3
16, 6 months–16, 11 months	-180	-898	-1,389	4	4
17 years–17, 5 months	-377	-1,883	-4,168	1	1
17, 6 months–18 years	-210	-1,049	-2,103	2	2

Note. The adjusted ratio ratios are from a model stratified by age and adjusted for highway fuel use, other highway-related laws, other GDL core components, state, and state- and age-specific linear trends, seasonality, unemployment, and contemporaneous age 20–24, 25–39, 40–59, and 60 or older driver fatal crash involvement rates. Boldface calibrations were those associated with the largest net reductions in fatal crashes for each component. GDL = Graduated driver licensing.
[a]Average based on the 5-year period 2003–2007. [b]Having no minimum number of supervised driving hours was the calibration associated with the largest net reduction in fatal crashes.

Although the effects associated with the various GDL component calibrations were found to differ according to the specific age of the teens, an alternative approach used to estimate the net effects associated with these components on 16–19 year olds as a group was to re-run the model without the component × age interactions. Such a model yields effect estimates for each GDL component calibration, combined across all the teen age groups, which are still adjusted for the same age- and state-specific confounders. The only statistically reliable rate ratios resulting from this model (Table 32) were that for learner permit holding periods lasting 9–12 months (RR = 0.88, 95% CI = 0.79, 0.99) and that for requiring 50–60 hours of supervised driving practice (RR = 1.11, 95% CI = 1.03, 1.21). However, two of the estimates were marginally reliable—that for requiring 20 or fewer hours of supervised driving practice (RR = 1.08, 95% CI = 1.00, 1.18) and that for granting unrestricted licensure at ages beginning from 17 years–17, 5 months (RR = 0.84, 95% CI = 0.69, 1.01).

Based on using the results from the no-age interaction model to calculate net attributable 16–19-year-old driver fatal crash involvements, the rankings of the calibrations within each component were found to be the almost the same as those resulting from the model including the GDL component × age interactions. The exceptions were for the two driving restriction components, for which there were some minor variations in the rankings of the calibrations. The calibration for each component deemed optimal because it had the lowest rank—meaning it was associated with the largest net estimated driver fatal crash reduction—was the same for both models. The net crash reduction rankings across all components were also similar between models, though there were again some differences. In the majority of cases the differences were only a one rank change (e.g., from rank 4 to rank 5). While the attributable fatal crash involvement savings estimates are fairly similar to those resulting from the model with the GDL component × age interactions, the conclusions based on the individual rate ratios are dramatically different. This again underscores the importance of allowing effect estimates to vary by age group in studies of GDL program components in order to accommodate effect modification (interaction) by age.

Table 32. No-Age-Interaction Model Net 16–19-year-old Adjusted Rate Ratios and Fatal Crash Involvements Attributable to each GDL Program Core Component Calibration by Time Span, United States

GDL core component	Adjusted rate ratio	95% CI	p	CLR	Attributable fatal crash involvements			1996–2007 rank within component	1996–2007 overall rank
					Yearly average[a]	2003–2007	1996–2007		
Learner permit age (minimum)									
15 years–15, 5 months	1.08	0.94, 1.24	.2618	1.32	232	1,162	3,176	3	25
15, 6 months–15, 11 months	1.08	0.92, 1.26	.3445	1.37	89	447	909	2	23
16 years	0.98	0.82, 1.17	.8553	1.43	-11	-57	-154	1	11
Learner permit holding period									
< 3 months	0.99	0.94, 1.05	.8374	1.12	-1	-4	-36	3	15
3–4 months	1.00	0.93, 1.07	.9801	1.15	0	2	5	4	17
5–6 months	0.99	0.93, 1.05	.6924	1.14	-48	-241	-420	2	8
9–12 months	0.88	0.79, 0.99	.0286*	1.25	-131	-657	-1,099	1	4
Supervised driving hours (total)[b]									
≤ 20 hours	1.08	1.00, 1.18	.0575†	1.18	41	206	280	3	22
25–35 hours	1.02	0.95, 1.09	.5864	1.14	9	43	86	1	20
40 hours	1.06	0.98, 1.15	.1488	1.18	32	158	223	2	21
50–60 hours	1.11	1.03, 1.21	.0096*	1.18	218	1,089	1,857	4	24
Intermediate stage license age									
< 16 years	1.00	0.87, 1.14	.9507	1.31	-2	-8	-17	2	16
16 years–16, 5 months	1.10	0.94, 1.30	.2239	1.38	374	1,871	3,595	3	26
16, 6 months–17 years	0.96	0.79, 1.17	.6925	1.49	-21	-105	-159	1	10
Nighttime driving restriction									
≤ 10:00 pm	0.99	0.87, 1.12	.8316	1.28	-9	-43	-87	4	14
11:00 pm	0.94	0.77, 1.15	.5456	1.50	-74	-369	-634	1	6
12:00 am	0.99	0.82, 1.21	.9586	1.48	-12	-61	-114	3	12
1:00 am	0.95	0.79, 1.15	.6250	1.46	-28	-138	-291	2	9
Passenger driving restriction									
0 passengers, < 6 months	1.01	0.90, 1.14	.8075	1.27	3	17	28	4	19
0 passengers, ≥ 6 months	0.99	0.90, 1.08	.7681	1.19	-14	-68	-110	2	13
1 passenger, ≥ 6 months	0.94	0.87, 1.02	.1134	1.17	-97	-484	-601	1	7
2–3 passengers, ≥ 6 months	1.00	0.93, 1.09	.9275	1.17	2	9	15	3	18
Unrestricted license age									
16 years–16, 5 months	0.95	0.84, 1.07	.4000	1.29	-37	-185	-1,279	3	3
16, 6 months–16, 11 months	0.89	0.77, 1.04	.1405	1.34	-134	-670	-1,038	4	5
17 years–17, 5 months	0.84	0.69, 1.01	.0671†	1.46	-361	-1,806	-3,912	1	1
17, 6 months–18 years	0.88	0.74, 1.06	.1728	1.44	-200	-1,002	-1,927	2	2

Note. Referent levels are shown in prior tables; they are excluded here for brevity. The adjusted ratio ratios are from a model adjusted for highway fuel use, other highway-related laws, other GDL core components, state, and state- and age-specific linear trends, seasonality, unemployment, and contemporaneous age 20–24, 25–39, 40–59, and 60 or older driver fatal crash involvement rates. Boldface calibrations were those associated with the largest net reductions in fatal crashes for each component. GDL = Graduated driver licensing. 95% CI = 95% confidence interval for the adjusted rate ratios. CLR = Confidence limit ratio (ratio of upper and lower confidence limits).
[a]Average based on the 5-year period 2003–2007. [b]Having no minimum number of supervised driving hours was the calibration associated with the largest net reduction in fatal crashes.
*$p < .05$ (reliably estimated). †$p < .10$ (marginally reliably estimated).

CHAPTER 5

V. DISCUSSION

This manuscript attempted to be the most thorough and rigorous national study of GDL programs and program components to date. The findings help clarify the effects associated with specialized teen driver licensing systems in general, and GDL programs in particular, by attempting to obtain the least-confounded estimates of changes in 16–19-year-old driver fatal crash involvements associated with implementing different types of teen driver licensing systems and the various components of those systems. All prior multi-state studies of teen driver licensing systems and GDL core components have had methodological or analytical problems, or excluded age groups or core program components, which hampered making inferences about net GDL program effectiveness for all teen drivers. While no study is perfect, this study improved upon these prior studies by rigorously controlling for competing potential confounds, avoiding to the greatest extent possible the methodological and analytical mistakes identified in prior studies, representing the entire range of existing component calibrations, and simultaneously including the entire 16–19 year old "teenage driver" age spectrum such that the net effects associated with these programs could be ascertained.

A. Implications of the National Study of Teen Driver Licensing Systems (Aims 1, 2)

This study attempted to answer the most important question about specialized teen driver licensing systems: Is there a net overall reduction in “teen driver” crashes associated with implementing these programs? This question is important because although there is evidence that some teen driver licensing systems are associated with lower crash rates for some younger teens, there is also evidence that some teen driver licensing systems may be associated with higher crash rates for older teens. The answer to this question based on the current study is that specialized teen driver licensing systems, with the exception of those with only an intermediate licensing stage, are associated with net reductions in driver fatal crash incidence among 16–19 year olds. The largest net reductions were associated with three-stage GDL programs, particularly those with two driving restrictions during the intermediate licensing stage. While GDL programs were found to be associated with higher crash incidence for some older teens, overall the results suggest that the benefits of GDL programs in terms of reductions in 16- and 17-year-old driver fatal crash involvements outweigh the increases in older teen driver fatal crash involvements. The mechanisms by which GDL programs are associated with higher crash rates for some older teens are not understood, and the ecological design of the current study does not allow proper inquiry into these mechanisms. While there are competing possibilities, the most likely cause seems to be that some younger teens delay licensure until they are no longer subject to the GDL requirements (age 18 in most states), which would increase the proportion of beginning drivers among 18 and 19 year olds. While evidence presented earlier for one state (California) supports this hypothesis, the unavailability of reliable and valid teen licensure data for other states precludes doing a nationwide analysis to provide stronger evidence. Higher prevalence of alcohol use among 18 and 19 year olds could further exacerbate their already high crash risk during initial unsupervised driving, resulting in even higher crash rates among these novices than would be the case if they were licensed at age 16 or 17. However, the fact remains that any increase in crash rates among older teens associated with implementing GDL programs appears to be counterbalanced by even larger reductions among younger teens.

Though much was made earlier about potential residual confounding in prior multi-state studies of teen driver licensing systems, most of the estimates of effect from the current study did not differ all that much where comparisons could be made to those from prior multi-state studies. The most complex specialized teen driver licensing systems, three-stage GDL programs, were found to be associated with 16% and 26% lower fatal crash incidence among 16 year olds, depending on whether there were one or two driving restrictions during the intermediate licensing stage, respectively. These are comparable to 21% lower 16-year-old driver fatal crash incidence for programs with six or seven GDL components from Chen et al. (2006), 19% lower 16-year-old driver fatalities from Vanlaar et al. (2009), and 18% and 41% lower 16-year-old driver fatal crash incidence for programs with IIHS ratings of “Fair” and “Good” from McCartt et al. (2010). Only the estimates from the McCartt et al. (2010) study were disparate from the current findings, and that study seemingly provided the least amount of control for potential sources of confounding. The study findings support prior research showing that GDL programs are indeed associated with lower crash rates for 16 year olds. In addition, two-stage systems with longer learner permit holding periods (≥3 months) were also found to be reliably associated with 12% lower 16-year-old fatal crash involvement rates, which is new to the literature.

Specialized teen driver licensing systems were associated with smaller net reductions among 17-year-olds. GDL programs with two driving restrictions during the intermediate licensing stage were associated with 9% lower 17-year-old fatal crash incidence, but those with only one driving restriction during the intermediate licensing stage were not reliably associated with a change in incidence. The point estimate for GDL programs with one restriction were, if anything, consistent with only a small directional 2% reduction in incidence. These are comparable to 0% change in 17-year-old driver fatalities from Vanlaar et al. (2009), and 3% and 19% lower 17-year-old driver fatal crash incidence for programs with IIHS ratings of "Fair" and "Good" from McCartt et al. (2010). Again the estimates are not that dissimilar from Vanlaar et al. (2009) given that those authors combined all GDL programs into a single estimate, but the McCartt et al. (2010) estimates again seem to overestimate the magnitude of GDL program effect. One consistent finding across all these studies is that GDL programs have a smaller effect, if any, on 17 year olds than on 16 year olds. The facts that the current study obtained separate estimates for weaker and stronger GDL programs, and that comparisons were made relative to having no specialized teen driver licensing system, may account for why the current study was able to detect a directional effect associated with the stronger GDL programs on 17 year old incidence when Vanlaar et al. (2009) did not find any evidence of an association. Interestingly, two-stage systems with only short learner permit holding periods (<3 months) were also found to be reliably associated with 12% lower 17-year-old fatal crash incidence, which is a new contribution to the literature.

The reasons why GDL programs are associated with smaller effects for 17 year olds than for 16 year olds have not been well addressed, which may explain why published studies of GDL programs often exclude these somewhat older teens. One possible explanation for this finding is that the combination of minimum learner stage entry ages and minimum learner permit lengths as part of GDL programs shifts teens who may have otherwise been licensed to drive unsupervised at age 16 to being licensed at age 17 instead. If true, this would tend to decrease the proportion of licensed 17 year olds with prior driving experience after GDL, which would increase their per capita crash rates and dilute any benefits from other GDL program components. Another possible explanation is that a smaller proportion of 17-year-old drivers than 16-year-old drivers are subject to specific GDL components in many states because they were already subject to those components at a younger age. For example, in a state with a 6-month passenger restriction, a smaller proportion of 17-year-old than 16-year-old drivers might be restricted from transporting passengers because some portion of the 17 year olds would have already completed their 6-month restriction while they were age 16. If so, this would reduce any crash savings associated with the restriction, and hence GDL programs as a whole, for 17 year olds. The degree to which this differential exists depends on the specific calibrations of the other GDL components in the state and historical trends in licensure rates by age (e.g., whether teens historically tend to be licensed at age 16, 17, or some other age in that state). Because the proportions of 16 and 17 year olds who are actively subject to different GDL components varies, likely with fewer 17 year olds subject to various

GDL components at any one time, finding smaller effects associated with GDL programs for 17 year olds could simply be a matter of less active program influence on 17 year olds. One other possibility, which has some empirical support, is that GDL programs are associated with smaller effects for 17 year olds because of self-selection bias. Specifically, the types of teens who wait until they are age 17 or even 18 to be licensed may differ from those who seek licensure at age 16. For example, they may have different driving needs and exposure profiles. The ecological design of the current study is not conducive to exploring such hypotheses, though one long-term cohort study comparing 17 year olds licensed to drive unsupervised before and after the implementation of a GDL program found no change in their crash incidence, whereas the GDL program was associated with lower crash incidence for 16 year olds licensed after the program was implemented (Masten & Foss, 2010). This suggests that some of the reduced effect associated with GDL programs for 17 year olds may indeed be a result of underlying differences between teens who seek licensure at different ages. Regardless, the current study does provide some evidence that stronger GDL programs with two restrictions during the intermediate licensing stage are associated with lower 17 year old fatal crash incidence, though the association is weaker than that for 16 year olds.

This is the first multi-state GDL study to demonstrate a *reliable* increase in fatal crash incidence for some older teens associated with implementing these programs, though at least one prior single-state study suggested this effect exists (Males, 2007). GDL programs were found in the current study to be reliably associated with increased 18-year-old driver fatal crash incidence of 10% (one driving restriction during the intermediate licensing stage) and 12% (two such restrictions). However, the current manuscript is not the first multi-state study to provide *directional* evidence of a negative effect associated with GDL programs on some older teens. Vanlaar et al. (2009) found that GDL programs were directionally, but not reliably, associated with an 8% increase in 18-year-old driver fatalities, and McCartt et al. (2010) found a directional 3% increase and a directional 4% decrease in 18-year-old driver fatal involvements for GDL programs with IIHS ratings of “Fair” and “Good,” respectively. Neither of the GDL point estimates for 19 year olds in the current study was reliable, with estimates of 0% and 5% higher incidence under GDL programs with one and two restrictions, respectively. Similarly, neither Vanlaar et al.’s (2009) 6% increase in 19-year-old driver fatalities nor McCartt et al.’s (2010) estimates of a directional 2% increase and directional 3% decrease in 19-year-old driver fatal crash involvements for GDL programs with IIHS ratings of “Fair” and “Good” were statistically reliable. Overall it seems that whatever negative effect GDL programs may have on 18 year olds, this effect is smaller, if there is any effect, for 19 year olds. This pattern of diminishing negative effect is consistent with a mechanism whereby GDL programs are associated with higher older teen driver fatal crash rates because some younger teens delay licensure until age 18 to avoid the requirements of GDL programs, because the expected negative effect associated with such a shift would be greater for 18 year olds than 19 year olds. This is consistent with the experience in California in that the post-GDL licensing rates for 16 and 17 year olds are lower, but more California teens are being licensed at ages 18 and 19 than before GDL. Teens licensed at ages 18 and 19 do not receive any potential benefits of mandatory driver education and training because they are not required of persons age 18 or older. Hence, higher proportions of older teens in California are beginner drivers after GDL than beforehand, which would likely increase their per capita crash rates. This pattern may be similar in other states, but the lack of quality national licensing data for teens prevents further systematic inquiry.

The purpose for coding the teen driver licensing systems using both stronger and weaker strategies was to be able to determine whether taking into account the quality of key GDL components made a difference in the effect estimates for three-stage GDL programs. In almost all cases, applying these minimum criteria to the length of learner permit holding periods and the rigor of nighttime and passenger restrictions was inconsequential. As might be expected, the stronger coding strategy directionally increased the strength of associations for three-stage GDL programs with two driving restrictions across all teen age groups, but the differences compared to estimates from the weaker coding strategy were small. The rate ratios for GDL programs never differed by more than 4% between the stronger and weaker coding strategies. The largest difference between the weaker and stronger estimates for *any* teen driver licensing system was the 10% difference for two-stage intermediate-stage-only systems for 16 year olds, which is also the only case where the estimate changed direction. The results here suggest that it does not make much difference whether criteria are applied to these components or whether they are simply accepted at face value when coding types of teen driver licensing systems in multi-state studies of GDL programs. This is also interesting because it may have implications about the relevance of subjective GDL program quality coding schemes such as the one developed by IIHS. The program components associated with the largest net crash reductions, and which therefore might be used to *empirically* create a program quality rating scheme are discussed below in regard the GDL program core component analysis.

B. Implications of the National Study of GDL Program Core Components (Aims 3 & 4)

This study also tried to determine which of the seven GDL program core components are associated with changes in fatal driver crash involvement rates of 16, 17, 18, and 19 year olds, how these associations varied as a function of the specific calibrations of the components, and which calibration for each component was associated with the largest net reduction in 16–19-year-old (combined) fatal crash involvements. It is the first study to simultaneously make adjusted comparisons among the spectrum of existing calibrations for all seven GDL core components and that also included all 16–19 year old "teen driver" age groups. The estimates of net changes in 16–19-year-old driver fatal crash involvements from 1996–2007 attributable to the different calibrations of each GDL component suggested that the calibration for each component associated with the largest net crash savings is:

1. A minimum learner stage entry age of 16 years;
2. A minimum learner permit holding period of 9–12 months;
3. No minimum number of required supervised driving hours;
4. An intermediate licensing stage starting at age 16.5–17 years;
5. A nighttime driving restriction starting at 11:00 pm;
6. A passenger restriction allowing no more than one teen passenger that lasts for 6 months or longer; and
7. Unrestricted licensure starting at age 17–17.4 years.

The GDL core component calibrations associated with the top four largest net fatal crash reductions from 1996–2007 all concern the age at which unrestricted licensure was granted, suggesting that this is the most important component of teen driver licensing systems. Granting unrestricted licensure at any age older than 15 years was directionally, and in most cases reliably, associated with lower driver fatal crash incidence for 16 and 19 year olds, but directionally, and in most cases reliably, higher incidence for 17 year olds. Unrestricted license ages were not reliably associated with driver fatal cash incidence for 18 year olds. There is no obvious explanation for why delaying unrestricted licensure would be associated with higher fatal crash incidence for 17 year olds, but lower incidence for some other teen age groups. To check whether this finding was possibly the result of multicollinearity with the intermediate licensing age component, the final model was replicated without intermediate licensing age (Table 35 in Appendix A). The patterns of effects for unrestricted licensing ages from this reduced model were not materially different from those in the full model, suggesting that the disparate findings for 17 year olds were not a result of multicollinearity. The only other study to which these findings could be compared was McCartt et al. (2010). They found that older minimum licensing ages, which represented a combination of both intermediate and full licensing ages in their study, was reliably associated with lower 16-year-old driver fatal crash incidence, but only a small directional trend towards higher 17-year-old incidence. The disparate findings regarding minimum unrestricted licensing ages for 17 year olds may be important for understanding why GDL programs overall are associated with smaller effects for 17 year olds than 16 year olds. It also suggests the need to consider possible unintended negative consequences associated with raising minimum licensing ages, as has recently been suggested by some traffic safety experts (Williams, Chaudhary, Tefft, & Tison, 2010), though the net effect across all teen drivers indicates that older unrestricted ages reduce driver fatal crash involvements overall.

The GDL core component calibration associated with the next largest net reduction in 16–19-year-old driver fatal crash incidence was the length of the learner permit holding period. Only learner permits with holding periods lasting 5–6 months and 9–12 months were found to be associated with lower 16- and 17-year-old incidences. No reliable changes in incidence were found for 18 or 19 year olds for learner permit holding periods. Finding learner permits with 5 month or longer holding periods to be associated with overall net reductions in teen driver fatal crash incidence makes logical sense, given the clear causal mechanisms for reduced teen driver fatal crashes and surety of administration associated with their use. Learner permit holding periods could be associated with crash reductions through four non-exclusive mechanisms: (a) reducing the amount of driving by delaying licensure, (b) reducing the number of drivers by decreasing licensure rates, (c) increasing driving skill by allowing more practice under controlled conditions, and (d) making initial driving safer because supervised drivers have few crashes. The enforcement of learner permit holding periods is absolute in that they are programmatic rather than being dependent on parental involvement or law enforcement to obtain compliance under two of these four crash reduction mechanisms.

The findings regarding the effects associated with 5-month or longer leaner permits in the current study are contrary to those from prior multi-state studies. Chen et al. (2006) found that learner permit holding periods of 3 months or longer (all combined) were not alone associated with a reliable change in 16-year-old fatal crash involvements. McCartt et al. (2010) found a small, but not statistically reliable, reduction in 16-year-old fatal crash incidence associated with longer learner permit holding periods, but reliably higher 17-year-old incidence. Overall they concluded that learner permit length is not associated with fatal crash incidence for 15–17-year-olds (combined). Given the logical causal mechanisms linking longer learner permit periods with reduced crash incidence, it is curious that these prior studies found no crash reductions associated with their lengths. When developing the models for the current study it was serendipitously discovered that learner permit holding periods were indeed not reliably associated with crash incidence when state-specific trends were not adjusted in the model, and when trend adjustments were not made separately for 16 and 17 year olds. Hence, it would also be expected that models in which a single trend estimate is used across all states or for all teen age groups would not identify the crash reductions associated with 5 month or longer learner permit holding periods that were found in the current study. Neither of the prior studies just discussed adjusted for state-specific trends, which probably explains the disparate findings—the results they report are likely confounded by varying state historical trends in teen fatal crash incidence that may hide the reduction in crash involvements associated with longer learner permit holding periods. The current study adjusted for both state- and age-specific trends, and hence the findings suggest that learner permit holding periods of 5 months or longer are indeed important components of GDL programs that are associated with large net crash reductions for teen drivers.

The component associated with the next largest net reduction in 16–19-year-old fatalities involves nighttime driving restrictions. However, the restriction start times associated with crash reductions were not consistent across the teen age groups. Only nighttime driving restrictions starting at 10:00 pm or earlier were reliably associated with lower 16-year-old fatal crash incidence, and no start times were reliably associated with changes in 17- or 19-year-old incidence. While all restriction start times were directionally consistent with lower 18-year-old incidence, only the estimates for restrictions starting at 11:00 pm and 1:00 am were marginally reliable. It is difficult to make comparisons to other multi-state studies because the present one parameterized nighttime driving restrictions in the analysis as nominal categories based on start time, while prior studies either used dichotomous categories (any nighttime driving restriction vs. none) or continuous hours of restricted time. Chen et al. (2006) did not find that nighttime driving restrictions alone were associated with lower 16-year-old fatal crash incidence, which might be explained by the fact that they crudely lumped all start times together in the study. McCartt et al. (2010) found earlier nighttime driving restriction times to be associated with lower fatal crash incidence among both 16 and 17 year olds, with an apparently stronger association for 16 year olds than for 17 year olds. The manner in which they coded start times in the analysis (linearly) precluded finding that some start times were associated with reductions while others were not. Hence, the best that can be said about the current findings is that they are consistent with McCartt et al. (2010), but not Chen et al. (2006), in finding that early nighttime driving restriction start times are associated with lower incidence among 16 year olds. However, the current findings differ from McCartt et al. (2010) in that no reliable association of nighttime driving restrictions and crash incidence was found for 17 year olds. The differences in findings may be due to using different parameterization schemes, state- and age-specific confounding in these prior studies, or other methodological and analytical choices that differ between the studies. That GDL programs overall are associated with smaller crash reductions for 17 year olds than 16 year olds may be due, at least in part, to the fact that nighttime driving restrictions do not appear to be associated with reductions for the former. This finding is consistent with the notion that fewer 17 year olds would be subject to nighttime restrictions because they already completed their restriction requirement while they were 16 years old.

The estimates of net attributable crashes across all teen drivers help clarify the findings regarding nighttime driving restrictions from the current study. Specifically, nighttime driving restrictions, regardless of start time, were all directionally consistent with fewer net 16–19-year-old crashes. The net estimate of crash savings was largest for nighttime driving restrictions starting at 11:00 pm, followed by those starting at 12:00 am, then 1:00 am, and finally 10:00 pm or earlier. Intuitively it would seem like earlier nighttime driving restriction start times would be associated with the largest crash reductions because they target a larger proportion of actual teen driving exposure. This expected pattern was found to be true only among restrictions starting at 11:00 pm or later. The crash savings estimates associated with nighttime driving restrictions starting at 11:00 pm or later appear to be primarily driven by the marginally reliable beneficial rate ratios for 18 year olds, given that none of the 11:00 pm or later start times were reliably associated with changes in incidences among 16 or 17 year olds. Overall the results suggest that nighttime driving restrictions are an important component of GDL programs, but the mechanism by which they may affect teen driver crash rates is more complex than originally considered. The 11:00 pm start time found to be associated with the largest net crash savings seems to represent the best balance point for weighing differential effects across teen age groups.

The GDL core component calibration associated with the next largest net reduction in 16–19-year-old driver fatal crash incidence was in regard to passenger driving restrictions. Only passenger restrictions allowing no more than one teen passenger and lasting for a period of 6 months or longer were found to be reliably associated with lower 16- and 17-year-old incidence. No passenger restriction calibrations were reliably associated with changes in 18- or 19-year-old incidence. These findings are contrary to those from McCartt et al. (2010) who found that passenger restrictions allowing zero passengers were reliably associated with lower driver fatal crash incidence among both 16 and 17 year olds. In addition, they found that those allowing only one teen passenger were reliably associated with lower incidence among 17 year olds, but only directionally lower incidence among 16 year olds, though the effect estimates for both were much smaller than those for restrictions disallowing any teen passengers. On the contrary, the current study findings suggest that allowing teens to transport one teen passenger may save more crashes among 16–19-year-olds than would completely disallowing them from transporting any teen passengers. While this may seem illogical given what is known about the higher crash risk of teen drivers when they transport other teens (Chen et al., 2000), one possible explanation for this finding could be that young teen drivers may be more likely to adhere to GDL program components and restrictions that they deem to be more reasonable (Goodwin & Foss, 2004; Goodwin et al., 2006). Hence, allowing them to experience somewhat higher risk associated with transporting one teen passenger may better shield them from the much higher risks associated with two or more passengers because compliance with the restriction is required to achieve any crash reduction. Another possible explanation is that because teens are not allowed to drive with other teens under zero-passenger restrictions, such restrictions may increase the number of teen drivers required to transport the same number of teens to a given destination. If so, this would be associated with more teen driver crash exposure (i.e., increase the numbers of teen drivers driving), and would hence tend to dilute the savings associated with such restrictions.

The minimum age at which teens are allowed to begin supervised learner driving (typically by obtaining a learner permit) was the GDL core component calibration associated with the next largest net reduction in 16–19-year-old driver fatal crash incidence. Compared to allowing teens to start supervised learning at an age younger than 15, only a learner stage entry age of 16 years was associated with lower net incidence across 16–19 year olds. Interestingly, requiring that teens be age 15 or older to begin the learner stage was not reliably associated with different 16-, 17-, or 19-year-old fatal crash incidence, but was reliably or marginally associated with higher 18-year-old crash incidence. This pattern of findings suggests two things. First, the net reduction in 16–19-year-old crash incidence associated with making teens wait until age 16 to begin the learner stage is due to cumulative, but unreliable, age-specific effects for 16, 17, and 19 year olds that more than ameliorate the marginally reliable increase associated with this learner age among 18 year olds. Second, older learner stage entry ages may be one of the factors that influence whether younger teens wait until age 18 to be licensed. Overall the findings support a minimum learner stage entry age of 16, though requiring teens to wait until this age to begin learning to drive is also associated with marginally higher 18-year-old driver fatal crash incidence.

The GDL core component calibration associated with the next largest net crash reduction among 16–19 year olds was the age at which teens are first allowed to drive unsupervised, but subject to license restrictions, during an intermediate licensing stage. Specifically, having an intermediate licensing stage where teens can begin driving unsupervised starting between 16.5 and 17 years was the only intermediate licensing stage minimum age associated with a net crash reduction across 16–19 year olds. This intermediate licensing stage entry age conveniently fits with the calibrations associated with the largest net crash reductions identified earlier for minimum learner stage entry ages and learner permit lengths—16 years and 9–12 months, respectively. Intermediate licensing stage entry ages younger than 16.5 years were reliably associated with higher fatal crash incidence among 16 year olds, but curiously none of the intermediate stage ages were reliably associated with 17-year-old incidence. Conversely, intermediate licensing ages of 16 or older were reliably associated with higher fatal crash incidence among 18 year olds. With regard to 19 year olds the results indicated that an intermediate licensing stage entry age of 16.5 years or older was reliably associated with lower incidence. These findings are interesting in that they mirror the general findings for GDL programs overall—lower crash rates for 16 year olds and higher crash rates for 18 year olds. The referent group for this component was unique from the other age-based components in that it was “no intermediate licensing stage” rather than a younger age. Given that having an intermediate licensing stage was defined as having a nighttime or passenger driving restriction—two other core GDL components—there was concern that the results associated with the intermediate licensing stage age might be affected by multicollinearity. To address this concern, the final component analysis was replicated without the intermediate licensing age component to see how the effect estimates of the other component calibrations changed (Table 35 in Appendix A). The resulting rate ratios tended to show weaker nighttime driving restriction and unrestricted licensing age effects for some age groups (defined as a change in the rate ratio of at least 10%), but the majority of the rate ratios changed little.

The final GDL core component, the minimum number of hours that teens are required to drive while supervised, was not associated with a net reduction in 16–19-year-old fatal crash involvements. In no instance were minimum numbers of hours of required supervised driving practice reliably associated with a reduction in the driver fatal crash incidences for any of the individual age groups. At best, minimum hours of supervised driving are associated with no change in incidence for individual age groups of teen drivers, though in some instances particular hours requirements were actually reliably associated with higher incidences. This finding is troubling because supervised driving hours are considered by many to be one of the seven core components of GDL programs. The strange pattern of findings—particularly finding so many reliable estimates for 19 year olds who are temporally furthest away from such a requirement—resulted in further modeling intended to determine if the results were spurious. In addition to the series of re-analyses excluding the various age-based components (Table 35 in Appendix A), which did not seem to implicate multicollinearity, the component analysis was replicated using the driver fatal crash rates of 40–59 year olds as the outcome (Table 36 in Appendix A). If this analysis suggested reliable increases in 40–59-year-old driver fatal crash incidence associated with supervised driving hours requirements, it would imply that the results for teens were a result of residual historical confounding or some artifact of the coding or modeling procedures. However, with the exception of a meager 4% increase associated with the 25–35 hour requirement, there was no indication that the supervised driving hours results reported for teen drivers were the result of residual confounding or some strange pattern in general among the quarters involved in these effects.

Assuming that supervised driving hours requirements are associated with more teen driving exposure (albeit supervised), it is possible that such requirements would be associated with some meager increase in crashes. This seems unlikely, however, given that teen crash rates are extremely low when they are supervised by adults (Mayhew et al., 2003; Williams, 2003). Of all the GDL core components, requiring additional supervised driving practice is both the simplest and cheapest to implement as it requires no significant programming changes on the part of licensing agencies and relies on parents for completion and enforcement. All the evidence thus far that such requirements actually change the numbers of hours that teens practice is based on self-reports from parents and teens (e.g., Williams, Nelson, & Leaf, 2002) and it might be the case that supervised driving hours requirements are not tied to the hours of practice that teens actually receive. That is, parents may consistently give their teen learners the amount of supervised practice that they deem necessary for safe driving, or not, regardless of what the official hours requirements might be according to the GDL programs. Though this is conjecture until further evidence emerges, some parents admit deviating from supervised driving hours requirements, even when they self-report this information (Williams et al., 2002). The current study findings suggest that requirements for minimum supervised driving hours are not reliably associated with lower driver fatal crash incidence and this component may not be an important part of GDL programs. Given that the literature about the effects of supervised driving practice on teen driver crash risk is inconclusive, though scanty, this may simply be the reality (Simons-Morton & Ouimet, 2006).

C. Methodologic Investigation of the Variation in Results due to Choice of Adult Covariates (Aim 5)

The choice of whether, and if so which, adult fatal crash rates to use as covariates to remove residual state-specific confounding (Aim 5) was inconsequential in most instances. None of the differences among the licensing system rate ratios were 10% or higher across the models in which the adult age group crash rate covariates varied, and in most cases the differences were small if there were any differences at all. In addition, the confidence limit ratios were similar across these models, indicating little difference in the precision of the estimates across models. However, these findings should not be interpreted to mean that it does not really matter which, if any, adult fatal crash rate covariates are used in similar studies. The current study did not rely on using contemporaneous adult driver fatal crash rates to control for all or most of the various sources of confounding affecting teen driver fatal crash incidence. Instead these confounding factors (e.g., state-specific trends, seasonality, economic conditions, and other highway-related law changes) were explicitly modeled where possible and the adult covariates were included only to adjust for residual sources of confounding that are not as easily captured (e.g., changes in enforcement levels and weather conditions). Finding that the adult fatal crash rate covariate choice was fairly inconsequential in this study suggests that when various sources of confounding are modeled independently, the choice of which adult age groups to use to remove residual sources of confounding is less important. Given the choice between explicitly including various sources of confounding in the model or using adult crash rates as a proxy for all or most sources of confounding, it is better use explicit controls because actual measures of the confounders provide better control for the confounding (Greenland, 1980; Kupper, 1984).

D. Study Limitations

A tremendous amount of effort was taken in this study to remove as many potential sources of confounding from the estimates as possible so that less-biased rate ratios for teen driver licensing systems and GDL core component calibrations could be obtained. It might be argued, however, that too many statistical controls were used or that they were too specific to the individual states and age groups. This seems most likely with regard to adjustments made to remove state- and age-specific trends and seasonality from the teen driver fatal crash involvement rates, as it has already been argued by McCartt et al. (2010) that these trends may be the result of increasingly rigorous teen driver licensing systems being implemented over time. Hence, they argue that any attempt to remove state-specific trends would remove GDL program effects. This may have some validity in studies that primarily include time points during which GDL programs were quickly spreading throughout U.S. states. The present study included over 10 years of pre-GDL data points so that the adjustments for state-age-group trends would not be based solely on time periods confounded with the implementation of GDL programs. The present study included the time period from January 1986 to December 2007 and the first GDL program was implemented in July 1996. The adjustments for state-specific trends and seasonality were done based on this entire time period and would therefore reflect long-term trends rather than just those potentially caused by the spread of GDL programs. Also, GDL effects are not likely to be seasonal. For these reasons, it seems less likely that the adjustments made for these confounding factors would have removed much of the GDL program effects.

The analyses are based on driver fatal crash involvements, which are different from driver fatalities. Young teen drivers tend to carry more passengers than other age groups, which increases their chances of being involved in a fatal crash because there tend to be more people per crash who could potentially die. This tendency may be further confounded by the fact that passengers are less likely to wear seat belts than are drivers. An attempt was made to replicate the final analyses based on using only driver fatalities to calculate the rates, like Vanlaar et al. (2009), but the complex models would not converge and it was not deemed desirable to sacrifice control of confounding to gain model stability. Driver fatal crash involvements are less rare than driver deaths, so the analyses presented here are based on larger samples and the models were therefore able to converge. The results of analyses based on driver fatalities, had they been successful, may have differed from those presented here, particularly the effects associated with passenger restrictions. In a larger sense, any results based only on fatal crashes may have differed from those that would be obtained based on less severe crashes. However, no national database of non-fatal crashes exists that would make it possible to identify crashes for individual U.S. states. The causes and contributing factors of fatal crashes differ from those of less serious crashes, particularly on high-risk behaviors such as alcohol use and excessive speeding. GDL programs are inherently less capable of influencing factors having to do with excessive behavior than crashes generally, because they seem less able to change attitudes, only driving (understanding) issues. Adjustments were made in the analyses to account for changes in other highway-related laws affecting alcohol use, speed limits, and seat belt use, but the extent to which these adjustments made the results more generalizable to less severe crashes in unknown.

Coding the teen driver licensing systems and components was a complicated and time-intensive process that involved compiling the work of others, original research of state vehicle codes and legislation, and communication with various state personnel. Some errors in existing coding sources were identified during this process, but others may have been missed and therefore would be propagated in this study. Coding errors should have been minimized by the thoroughness of the investigation and would likely have only a small, but unknown influence on the effect estimates.

One limitation that might affect the interpretation and generalization of the results is that the coding of components was based on the assumption that all teens seek unsupervised licensure through each state's system as early and quickly as possible, which is known to be untrue. For example, only 13% of California 16 year olds were licensed to drive unsupervised in 2007, whereas the percentage is over 60% in North Carolina. Furthermore, some teens drive without a license because of their inability to provide legal presence documentation, and the crash contributions of these drivers almost certainly differ across states. This assumption is common among studies like the present one because it supports an operational definition of the components that enables the analyses to be replicated. The effect of this assumption is unknown, but might have been incidentally controlled through adjustments made to control for overall differences in state- and age-specific driver fatal crash rates. It might seem desirable to have directly adjusted for differences in licensure rates to control for deviations from this assumption, if reliable licensure data had been available for all states, which they were not. However, one mechanism by which teen driver licensing systems likely affect teen crash rates is by delaying licensure and decreasing teen licensure rates. Hence, adjusting for changes in licensure volumes or rates over time would likely have removed important GDL program effects (i.e., licensure rates are on the causal pathway for GDL effects), which would yield rate ratios that underestimate actual program effects. The adjustments for overall state- and age-specific differences in crash incidence rates were used, in part, as surrogates for preexisting differences in licensure rates between states and age groups, as differences in licensure rates are probably a major reason why crash rates differ so much between states and teen age groups.

The analyses do not directly take into account any grandfathering regarding the implementation of GDL programs in different states. Some GDL program components, such as intermediate stage driving restrictions following a 12-month learner permit holding period, would not necessarily take effect until a year or more after the date the GDL program was actually implemented. Hence, the full influence of these effects would be realized gradually as higher proportions of affected teens become subject to the licensing systems. There are also transition effects that sometimes occur when implementing GDL programs that result in higher crash rates immediately before and after the programs are implemented, likely due to teens applying earlier than they would have otherwise to avoid being subject to the GDL programs. While the effects associated with both temporary transitions artifacts and gradual increases in program strength as more teens become subject to all program components were not directly modeled in this study, the long time periods analyzed both before and after most GDL programs and components were implemented were intended to smooth out these temporary effects so that the long-term averages would provide valid estimates. It could still be argued that the estimates presented here for some program components underestimate the true associations because the follow-up periods include some quarters when none or only a small percentage of teens were actually subject to particular components. This is not an entirely invalid point, though the fact that every component estimate was based on at least five states and at least 91 quarters suggests that the models had enough supporting data for the estimates to converge towards true values even with these temporary and delayed effects present.

The age-specific GDL components (learner permit age, intermediate stage license age, and unrestricted license age) are not considered by some experts to be core elements of GDL programs. It is also seemed possible that because intermediate stage license ages and unrestricted license ages are in some instances predictable from other program components, that including them both in the model along with the other components could lead to estimation problems. For example, it may seem to be the case that intermediate stage license ages are completely determined by the minimum ages for obtaining learner permits and the lengths of the learner permit holding periods. While this is often true, it is not always the case. As an example of the latter, from the date of implementation of the GDL program in July 1998 until the end of 2003, California had a minimum learner permit age of 15 years, a

6-month minimum learner permit holding period, and a minimum intermediate licensing age of 16 years. There were instances in almost every state during the study time period when the relations among other components did not determine the intermediate stage license age (or unrestricted license age), similar to this California example.

Nonetheless, to explore the degree to which multicollinearity might have affected the results, several exploratory analyses were completed in which the age-specific GDL components were excluded from the models in selected combinations (Table 35 in Appendix A). The results of these analyses did not suggest that there were problems with multicollinearity in the original analysis. The unexpected findings for supervised driving hours were thought to possibly be a result of such a problem, but the removal of the age-based components did not materially change the rate ratios for any of the supervised driving hours calibrations. In general the nighttime driving restriction estimates changed the most—and generally towards the null—when the age-based components were removed, suggesting that there was indeed some overlap between this restriction and the age-based components.

The intermediate stage license age and unrestricted license age components were also found to be independently associated with changes in teen driver fatal crash incidence, which suggests that these age-related components are indeed important parts of teen driver licensing systems. Whether the age-related components should be considered core components of GDL programs is irrelevant—the ages at which teens are allowed to enter the various stages of driving are strongly associated with crash incidence and therefore should be taken into account in a proper multi-state study of teen driver licensing systems and in designing GDL programs that are suitable for specific states. That is, whether they are "components" or "confounders" is a discussion to be left to GDL experts—the need to account for differences in crash incidence associated with these licensing age criteria exists regardless.

This study did not take into account the contextual factors regarding how the various components were implemented. While the rate ratios for each component were adjusted for the effects associated with all other components, they do not address how the components interact with each other. Therefore, the results of this study do not address for example how an 11:00 pm nighttime driving restriction works in conjunction with a zero-passenger limit or what a minimum age for intermediate driving means when the restrictions included during the intermediate licensing stage are trivial. GDL components and calibrations certainly interact with each other, but it is not possible to conduct an analysis of all possible configurations of the components because there are too few cases (state quarters) and too many missing cells to enable much more than a dichotomous categorization of the core components. Hence the results of this study do not necessarily speak meaningfully regarding how to calibrate an optimum GDL program for all circumstances, only how to best calibrate each individual component based on results from real-world programs that operate in different contexts. Empirical studies will never be able to determine which components and calibrations of those components work the best together, because such studies are necessarily limited to the combinations and calibrations that have at some point actually been implemented in one or more states. The analyses presented here add to our knowledge regarding which calibration for each component is associated with the largest net fatal crash savings given the varying and complex contexts in which they were implemented. However, while the findings help clarify which component calibrations have the highest potential for net driver fatal crash reductions across varying contexts, they do not necessarily indicate which combinations and calibrations of components would be optimal for designing a specific state's GDL program.

Not all GDL components are equally enforced with regard to compliance. For those that are not programmatic (e.g., learner permit ages) and therefore are dependent on parental involvement or law enforcement to obtain compliance (e.g., passenger driving restrictions), the enforcement certainly varies among states. Enforcement, or at least teens' perceptions about the likelihood of being caught for illegal driving activities, is likely an important factor that determines the effectiveness of some GDL components such as the intermediate licensing stage restrictions. This study did not explicitly address levels of enforcement of the non- programmatic components. To the degree that enforcement of driving-related laws in general equally affects adults and teens, the inclusion of adult driver fatal crash covariates would be expected to crudely model overall differences in enforcement across states and within states over time. However, the enforcement of GDL driving restrictions is typically secondary in nature (i.e., teens cannot be stopped solely because a law enforcement officer suspects they may be violating a driving restriction) and may be enforced differently than regular traffic laws with more certain safety nexuses. Given the potential importance of enforcement for achieving the effectiveness of some GDL components, a study of how component effects differ across varying levels of enforcement would be a valuable addition to the GDL literature.

Finally, this study was necessarily implemented using a quasi-experimental ecological design, which limits the extent to which the findings can be viewed as causal. It differs from a purely cross-sectional design in that before and after data were also used for each state to obtain the effect estimates, which is why it is best characterized as a cross-sectional time series design. This quasi-experimental design is inferior to a true experimental design for being able to make causal inferences from the findings, but it was not possible to use a true experimental design to study teen licensing systems in real-world settings. The cross-sectional time series design would yield confounded estimates if there are differences between states or within states over time that affect fatal crash involvements and are correlated with program components, and these differences were not adequately controlled in the analyses. While every attempt was made to identify potential sources of confounding and make appropriate adjustments in the analyses, to the extent that important confounders were excluded from the analyses the results are biased. The direction of this bias is not definitely known, but likely towards finding reductions associated with teen licensing programs that are spurious given the general tendency over time towards lower driver fatal crash involvement rates.

E. Overall Conclusions

GDL programs were reliably associated with 16–26% lower driver fatal crash incidence for 16 year olds, but 10–12% higher incidence for 18 year olds, dependent upon the number of license restrictions included during the intermediate licensing stage. GDL programs with two license restrictions during the intermediate licensing stage were marginally associated with 9% lower 17-year-old driver fatal crash incidence. The benefits of GDL programs in terms of reducing 16- and 17-year-old driver fatal crash involvements were found to outweigh the increased involvements among 18 year olds associated with such programs. Overall, 544 fewer net 16–19-year-old driver fatal crash involvements during the 12-year period since the first U.S. GDL program was implemented are attributable to having specialized teen driver licensing systems. The majority of the net crash reduction (470 involvements) is attributable to implementing three-stage GDL programs.

At least one calibration for each GDL program core component, except supervised driving hours, was associated with a net decrease in 16–19-year-old driver fatal crash involvements. The calibrations of the GDL program core components associated with the largest net 16–19-year-old driver fatal crash involvement savings are: (a) a minimum learner stage entry age of 16 years; (b) a minimum learner permit holding period of 9–12 months; (c) no minimum number of required supervised driving hours; (d) an intermediate licensing stage starting at age 16.5–17 years; (e) a nighttime driving restriction starting at 11:00 pm; (f) a passenger restriction allowing no more than one teen passenger that lasts for 6 months or longer; and (g) unrestricted licensure starting at age 17–17.4 years.

APPENDIX A: SUPPLEMENTARY STATISTICAL TABLES

Table 33. Teen Driver Licensing Systems Analysis Likelihood Ratio Tests

Source	*df*	Chi-square	*p*
Teen Age Group	3	287.20	<.0001*
State	50	292569.00	<.0001*
State × Age Group	150	11830000.00	<.0001*
Involvements Age 20–24	1	29.18	<.0001*
Involvements Age 25–39	1	1971.60	<.0001*
Involvements Age 40–59	1	677.43	<.0001*
Involvements Age 60+	1	2.06	.1516
Involvements Age 20–24 × State	50	2511314.00	<.0001*
Involvements Age 25–39 × State	50	1940000000.00	<.0001*
Involvements Age 40–59 × State	50	886335.00	<.0001*
Involvements Age 60+ × State	50	2633393.00	<.0001*
Involvements Age 20–24 × Teen Age Group	3	5348.19	<.0001*
Involvements Age 25–39 × Teen Age Group	3	1851.78	<.0001*
Involvements Age 40–59 × Teen Age Group	3	6105.28	<.0001*
Involvements Age 60+ × Teen Age Group	3	5893.19	<.0001*
Involvements Age 20–24 × State × Teen Age Group	150	317500000.00	<.0001*
Involvements Age 25–39 × State × Teen Age Group	150	85720000.00	<.0001*
Involvements Age 40–59 × State × Teen Age Group	150	82630000.00	<.0001*
Involvements Age 60+ × State × Teen Age Group	150	2261000000.00	<.0001*
Speed Limit Law	3	0.58	.9002
Speed Limit × Teen Age Group	9	3.03	.9633
Seat Belt Law	2	2.52	.2843
Seat Belt Law × Teen Age Group	6	9.83	.1319
Minimum Legal Drinking Age 21 Law	1	1.68	.1953
Minimum Legal Drinking Age 21 Law × Teen Age Group	3	3.13	.3728
Zero Tolerance Law	1	0.84	.3601
Zero Tolerance Law × Teen Age Group	3	1.22	.7477
BAC Law	2	4.10	.1288
BAC Law × Teen Age Group	6	8.65	.1944
Administrative License Suspension Law	1	0.74	.3896
Administrative License Suspension Law × Teen Age Group	3	4.01	.2606
Driver Licensing System	5	24.94	.0001*
Driver Licensing System × Teen Age Group	15	50.33	<.0001*
Quarter	3	48405.20	<.0001*
Quarter × State	150	24740000.00	<.0001*
Quarter × Teen Age Group	9	279375.00	<.0001*
Quarter × State × Teen Age Group	450	1114000000.00	<.0001*
Continuous Time (Year-Quarter)	1	7.64	.0057*
Continuous Time × State	50	3661574.00	<.0001*
Continuous Time × Teen Age Group	3	32.05	<.0001*
Continuous Time × State × Teen Age Group	150	94110000.00	<.0001*
Unemployment	1	220.98	<.0001*
Unemployment × State	50	752000000000000000.00	<.0001*
Unemployment × Teen Age Group	3	549.48	<.0001*
Unemployment × State × Teen Age Group	150	102800000.00	<.0001*
Annual Highway Fuel Use	1	20.79	<.0001*

Note. Likelihood ratio tests are for the model adjusted for highway fuel use, other highway-related laws, other driver licensing systems, state, age group, and state- and age-specific linear trends, seasonality, unemployment, and the contemporaneous driver fatal crash involvement rates of all adult age groups.
*$p < .05$ (reliably estimated). †$p < .10$ (marginally reliably estimated).

Table 34. GDL Program Core Components Analysis Likelihood Ratio Tests

Source	*df*	Chi-square	*p*
Teen Age Group	3	104.26	<.0001*
State	50	4436380.00	<.0001*
State × Age Group	150	158800000.00	<.0001*
Involvements Age 20–24	1	37.68	<.0001*
Involvements Age 25–39	1	1233.08	<.0001*
Involvements Age 40–59	1	654.65	<.0001*
Involvements Age 60+	1	0.99	.3197
Involvements Age 20–24 × State	50	43190000.00	<.0001*
Involvements Age 25–39 × State	50	13200000.00	<.0001*
Involvements Age 40–59 × State	50	29510000.00	<.0001*
Involvements Age 60+ × State	50	62160000.00	<.0001*
Involvements Age 20–24 × Teen Age Group	3	2808.33	<.0001*
Involvements Age 25–39 × Teen Age Group	3	1392.70	<.0001*
Involvements Age 40–59 × Teen Age Group	3	3163.68	<.0001*
Involvements Age 60+ × Teen Age Group	3	4058.75	<.0001*
Involvements Age 20–24 × State × Teen Age Group	150	1414000000.00	<.0001*
Involvements Age 25–39 × State × Teen Age Group	150	14100000000.00	<.0001*
Involvements Age 40–59 × State × Teen Age Group	150	9335000000.00	<.0001*
Involvements Age 60+ × State × Teen Age Group	150	260500000.00	<.0001*
Speed Limit Law	3	0.44	.9325
Speed Limit × Teen Age Group	9	4.16	.9007
Seat Belt Law	2	1.72	.4242
Seat Belt Law × Teen Age Group	6	5.00	.5440
Minimum Legal Drinking Age 21 Law	1	2.10	.1471
Minimum Legal Drinking Age 21 Law × Teen Age Group	3	4.56	.2071
Zero Tolerance Law	1	0.72	.3947
Zero Tolerance Law × Teen Age Group	3	0.47	.9253
BAC Law	2	5.11	.0778†
BAC Law × Teen Age Group	6	9.82	.1325
Administrative License Suspension Law	1	0.28	.5971
Administrative License Suspension Law × Teen Age Group	3	4.14	.2465
Minimum Entry Age	3	18.24	.0004*
Minimum Entry Age × Teen Age Group	9	20.54	.0149*
Mandatory Holding Period	4	20.15	.0005*
Mandatory Holding Period × Teen Age Group	12	17.74	.1237
Supervised Driving Hours	4	8.72	.0685†
Supervised Driving Hours × Teen Age Group	12	23.29	.0254*
Intermediate License Stage Age	3	30.97	<.0001*
Intermediate License Stage Age × Teen Age Group	9	40.81	<.0001*
Nighttime Driving Restriction	4	14.86	.0050*
Nighttime Driving Restriction × Teen Age Group	12	19.33	.0808†
Passenger Restriction	4	16.89	.0020*
Passenger Restriction × Teen Age Group	12	17.42	.1344
Unrestricted License Age	4	8.41	.0778†
Unrestricted License Age × Teen Age Group	12	52.46	<.0001*

Table 34. (Continued)

Source	*df*	Chi-square	*p*
Quarter	3	31653.30	<.0001*
Quarter × State	150	95400000000.00	<.0001*
Quarter × Teen Age Group	9	214361.00	<.0001*
Quarter × State × Teen Age Group	450	85100000000.00	<.0001*
Continuous Time (Year-Quarter)	1	4.70	.0302*
Continuous Time × State	50	650808.00	<.0001*
Continuous Time × Teen Age Group	3	31.02	<.0001*
Continuous Time × State × Teen Age Group	150	174000000000.00	<.0001*
Unemployment	1	206.45	<.0001*
Unemployment × State	50	55360000.00	<.0001*
Unemployment × Teen Age Group	3	419.21	<.0001*
Unemployment × State × Teen Age Group	150	3565000000.00	<.0001*
Annual Highway Fuel Use	1	16.18	<.0001*

Note. Likelihood ratio tests are for the model adjusted for highway fuel use, other highway-related laws, other GDL core components, state, age group, and state- and age-specific linear trends, seasonality, unemployment, and the contemporaneous driver fatal crash involvement rates of all adult age groups.

*$p < .05$ (reliably estimated). †$p < .10$ (marginally reliably estimated).

Table 35. Comparison of GDL Program Core Components Adjusted Rate Ratios With and Without Selected Combinations of the Three Age-Based Components

GDL core component	All components		No intermediate age component		No intermediate or unrestricted age components		No age components at all	
	Rate ratio	*p*	Rate ratio	*p*	Rate ratio	*p*	Rate ratio	*p*
16 year olds								
Learner permit age (minimum)								
15 years–15, 5 months	1.12	.2895	1.09	.3859	1.08	.3806		
15, 6 months–15, 11 months	0.98	.8791	0.94	.5999	0.94	.5516		
16 years	0.88	.3181	0.85	.2028	0.84	.1529		
Learner permit holding period								
< 3 months	1.05	.5355	1.08	.2061	1.09	.1302	1.10	.0650†
3–4 months	1.00	.9868	1.03	.6023	1.03	.6355	1.04	.4662
5–6 months	0.89	.0659	0.88	.0381*	0.88	.0165*	0.90	.0448*
9–12 months	0.74	.0010*	0.77	.0025*	0.77	.0004*	0.76	.0005*
Supervised driving hours (total)								
≤ 20 hours	1.03	.7570	0.96	.6499	0.95	.5334	0.95	.5432
25–35 hours	0.95	.3694	0.91	.0907†	0.92	.1013	0.91	.0852†
40 hours	1.14	.0415	1.11	.1629	1.11	.1505	1.09	.2265
50–60 hours	1.02	.6975	0.95	.3511	0.95	.2922	0.95	.3161
Intermediate stage license age								
< 16 years	1.29	.0058*						
16 years–16, 5 months	1.18	.0653						
16, 6 months–17 years	0.77	.0197*						
Nighttime driving restriction								
≤ 10pm	0.81	.0097*	0.85	.0896†	0.84	.0335*	0.83	.0220*
11pm	0.96	.7261	1.03	.7590	0.97	.7845	0.92	.3924
12am	1.04	.7222	**1.17**	.1009	1.12	.0903†	1.08	.1836
1am	0.91	.3594	**1.02**	.8540	0.96	.4381	0.98	.7027
Passenger driving restriction								
0 passengers, < 6 months	1.02	.7256	1.11	.0864†	1.09	.0926†	1.07	.1907
0 passengers, ≥ 6 months	0.91	.2911	0.91	.3005	0.91	.3022	0.92	.4511
1 passenger, ≥ 6 months	0.80	<.0001*	0.80	.0003*	0.80	.0002*	0.80	.0001*
2–3 passengers, ≥ 6 months	0.98	.7952	0.91	.1423	0.90	.0396*	0.89	.0280*
Unrestricted license age								
16 years–16, 5 months	0.89	.1072	0.93	.4168				
16, 6 months–16, 11 months	0.78	.0045*	**0.92**	.4228				
17 years–17, 5 months	0.74	.0293*	**0.89**	.4471				
17, 6 months–18 years	0.78	.0473*	0.85	.2655				

Table 35. (Continued)

GDL core component	All components		No intermediate age component		No intermediate or unrestricted age components		No age components at all	
	Rate ratio	*p*	Rate ratio	*p*	Rate ratio	*p*	Rate ratio	*p*
17 year olds								
Learner permit age (minimum)								
15 years–15, 5 months	1.06	.4681	1.06	.4432	1.10	.1414		
15, 6 months–15, 11 months	1.03	.7533	1.04	.7272	1.07	.4875		
16 years	0.93	.5872	0.93	.5811	0.95	.6967		
Learner permit holding period								
< 3 months	0.95	.3170	0.95	.2790	0.92	.1121	0.93	.1489
3–4 months	0.99	.8022	0.99	.8393	1.00	.9332	1.01	.8432
5–6 months	0.91	.0869†	0.92	.0989†	0.97	.6104	0.98	.7276
9–12 months	0.83	.0234*	0.83	.0235*	**0.92**	.2821	0.91	.2711
Supervised driving hours (total)								
≤ 20 hours	1.04	.4243	1.05	.2503	1.04	.3286	1.03	.4400
25–35 hours	1.06	.4702	1.07	.4553	1.05	.6088	1.05	.6069
40 hours	1.13	.0155*	1.13	.0134*	1.16	.0060*	1.15	.0154*
50–60 hours	1.05	.3863	1.05	.3012	1.00	.9744	1.00	.9384
Intermediate stage license age								
< 16 years	0.92	.5682						
16 years–16, 5 months	0.99	.9715						
16, 6 months–17 years	1.03	.8369						
Nighttime driving restriction								
≤ 10pm	0.97	.8189	0.96	.6162	1.00	.9819	1.00	.9831
11pm	0.99	.9418	0.98	.8469	1.00	.9795	0.98	.7918
12am	1.02	.9283	1.00	.9907	1.01	.8724	0.99	.8343
1am	0.94	.7219	0.93	.4205	0.92	.2388	0.94	.3541
Passenger driving restriction								
0 passengers, < 6 months	1.10	.3761	1.09	.4167	1.14	.2482	1.13	.2760
0 passengers, ≥ 6 months	0.98	.7950	0.98	.8096	0.97	.6523	0.98	.7662
1 passenger, ≥ 6 months	0.88	.0465*	0.89	.0501†	0.92	.1242	0.92	.1373
2–3 passengers, ≥ 6 months	1.03	.5172	1.04	.3775	1.04	.3467	1.03	.4282
Unrestricted license age								
16 years–16, 5 months	1.25	.0043*	1.22	.0136*				
16, 6 months–16, 11 months	1.53	<.0001*	1.48	<.0001*				
17 years–17, 5 months	1.25	.1075	1.22	.0997†				
17, 6 months–18 years	1.33	.0370*	1.31	.0284*				

Table 35. (Continued)

GDL core component	All components		No intermediate age component		No intermediate or unrestricted age components		No age components at all	
	Rate ratio	*p*	Rate ratio	*p*	Rate ratio	*p*	Rate ratio	*p*
18 year olds								
Learner permit age (minimum)								
15 years–15, 5 months	1.17	.0453*	1.16	.0698†	1.15	.1497		
15, 6 months–15, 11 months	1.25	.0089*	1.23	.0229*	1.21	.0730†		
16 years	1.20	.0743†	1.17	.1457	1.16	.2424		
Learner permit holding period								
< 3 months	1.01	.7302	1.02	.5960	1.02	.7144	1.03	.5447
3–4 months	0.99	.8680	1.03	.6982	1.01	.8441	1.01	.8987
5–6 months	1.03	.6573	1.04	.5057	1.03	.5466	1.03	.6084
9–12 months	0.85	.1028	0.91	.3379	0.90	.2677	0.91	.3063
Supervised driving hours (total)								
≤ 20 hours	1.04	.6480	1.02	.7720	1.02	.7806	1.01	.8450
25–35 hours	1.03	.5352	1.01	.8277	1.01	.7834	1.02	.6768
40 hours	0.90	.1877	0.90	.1889	0.90	.2237	0.90	.2229
50–60 hours	1.20	.0049*	1.16	.0170*	1.16	.0063*	1.15	.0048*
Intermediate stage license age								
< 16 years	1.08	.5971						
16 years–16, 5 months	1.33	.0149*						
16, 6 months–17 years	1.26	.0631†						
Nighttime driving restriction								
≤ 10pm	0.97	.7831	**1.07**	.5398	**1.10**	.4236	**1.10**	.4018
11pm	0.75	.0919†	**0.92**	.5269	**0.99**	.9388	**1.00**	.9956
12am	0.81	.1962	**0.99**	.9023	**1.05**	.4968	**1.04**	.5851
1am	0.80	.0977†	**0.95**	.5791	**1.02**	.6273	**1.03**	.5370
Passenger driving restriction								
0 passengers, < 6 months	0.87	.1254	0.95	.5593	**0.96**	.6251	**0.97**	.6513
0 passengers, ≥ 6 months	1.00	.9805	1.00	.9894	1.02	.8418	1.03	.6819
1 passenger, ≥ 6 months	0.99	.9426	1.00	.9644	0.97	.7423	0.99	.8395
2–3 passengers, ≥ 6 months	0.98	.7076	0.95	.3611	0.96	.4767	0.97	.4824
Unrestricted license age								
16 years–16, 5 months	0.92	.1824	0.86	.0361*				
16, 6 months–16, 11 months	0.87	.1897	0.87	.2020				
17 years–17, 5 months	0.88	.4030	0.92	.5608				
17, 6 months–18 years	0.94	.6437	0.94	.6540				

Table 35. (Continued)

GDL core component	All age components		No intermediate age component		No intermediate or unrestricted age components		No age components	
	Rate ratio	*p*	Rate ratio	*p*	Rate ratio	*p*	Rate ratio	*p*
19 year olds								
Learner permit age (minimum)								
15 years–15, 5 months	0.97	.5593	0.94	.3492	0.92	.1891		
15, 6 months–15, 11 months	0.98	.7050	0.94	.3899	0.92	.2527		
16 years	0.87	.1266	0.84	.0868†	0.82	.0478*		
Learner permit holding period								
< 3 months	0.97	.4994	1.00	.9138	1.00	.9138	1.00	.9677
3–4 months	1.02	.7514	1.03	.5316	1.03	.6296	1.03	.5881
5–6 months	1.07	.2154	1.03	.5840	1.01	.8146	1.02	.7555
9–12 months	1.07	.3753	1.07	.3047	1.05	.4930	1.04	.5213
Supervised driving hours (total)								
≤ 20 hours	1.22	.0006*	1.13	.1589	1.13	.1233	1.12	.0992†
25–35 hours	1.02	.5179	1.00	.9515	1.00	.9038	1.00	.9160
40 hours	1.14	.0132*	1.09	.1490	1.08	.1613	1.08	.1905
50–60 hours	1.16	.0060*	1.08	.1159	1.08	.1058	1.10	.0454*
Intermediate stage license age								
< 16 years	0.87	.2066						
16 years–16, 5 months	0.99	.9099						
16, 6 months–17 years	0.73	.0117*						
Nighttime driving restriction								
≤ 10pm	1.14	.1077	1.05	.6100	**1.02**	.8006	**1.02**	.7916
11pm	1.08	.4885	**0.97**	.7042	**0.92**	.2505	**0.92**	.2248
12am	1.10	.3656	**0.99**	.9253	**0.95**	.3026	**0.95**	.3286
1am	1.16	.1579	1.06	.4012	**1.01**	.8276	**1.03**	.5469
Passenger driving restriction								
0 passengers, < 6 months	1.06	.5357	1.03	.6273	1.01	.8494	1.00	.9694
0 passengers, ≥ 6 months	1.01	.9117	1.02	.6594	1.03	.5263	1.01	.7962
1 passenger, ≥ 6 months	1.03	.5052	1.03	.6068	1.02	.6995	1.01	.8734
2–3 passengers, ≥ 6 months	1.00	.9736	0.91	.2308	**0.90**	.1138	**0.89**	.0699†
Unrestricted license age								
16 years–16, 5 months	0.80	<.0001*	0.79	<.0001*				
16, 6 months–16, 11 months	0.65	<.0001*	**0.73**	<.0001*				
17 years–17, 5 months	0.63	<.0001*	**0.75**	.0012*				
17, 6 months–18 years	0.65	<.0001*	**0.72**	.0017*				

Note. The adjusted ratio ratios are from a model stratified by age and adjusted for highway fuel use, other highway-related laws, other GDL core components, state, and state- and age-specific linear trends, seasonality, unemployment, and contemporaneous age 20–24, 25–39, 40–59, and 60 or older driver fatal crash involvement rates. GDL = graduated driver licensing. Boldface rate ratios differed by 10% or more from the model with all GDL program core components.
*$p < .05$ (reliably estimated). †$p < .10$ (marginally reliably estimated).

Table 36. Adjusted 40–59-Year-Old Driver Fatal Crash Involvement Rate Ratios by GDL Program Core Component, United States 1986–2007

GDL core component	No adult crash covariates				All other adult age covariates			
	Adjusted rate ratio	95% CI	*p*	CLR	Adjusted rate ratio	95% CI	*p*	CLR
Learner permit age (minimum)								
15 years–15, 5 months	1.04	0.95, 1.14	.4415	1.04	1.03	0.96, 1.10	.4343	1.14
15, 6 months–15, 11 months	1.07	0.97, 1.18	.1627	1.07	1.01	0.93, 1.08	.8898	1.16
16 years	1.06	0.95, 1.18	.3126	1.06	1.01	0.92, 1.10	.8826	1.20
Learner permit holding period								
< 3 months	1.02	0.97, 1.08	.3991	1.02	1.02	0.99, 1.06	.2268	1.08
3–4 months	0.95	0.90, 0.99	.0258*	0.95	0.96	0.92, 1.00	.0376*	1.08
5–6 months	0.98	0.93, 1.03	.3484	0.98	0.99	0.95, 1.03	.6127	1.09
9–12 months	0.92	0.83, 1.02	.1213	0.92	0.96	0.88, 1.04	.3180	1.19
Supervised driving hours (total)								
≤ 20 hours	1.06	0.99, 1.15	.0960†	1.06	1.03	0.97, 1.10	.3126	1.14
25–35 hours	1.07	1.02, 1.12	.0080*	1.07	1.04	1.00, 1.07	.0366*	1.07
40 hours	1.02	0.97, 1.08	.4334	1.02	1.00	0.96, 1.05	.8639	1.09
50–60 hours	1.05	0.99, 1.13	.1200	1.05	1.03	0.98, 1.09	.2378	1.11
Intermediate stage license age								
< 16 years	1.00	0.86, 1.16	.9883	1.00	1.02	0.92, 1.14	.6660	1.24
16 years–16, 5 months	1.05	0.91, 1.21	.4914	1.05	1.08	0.96, 1.22	.2091	1.27
16, 6 months–17 years	1.06	0.92, 1.23	.3863	1.06	1.08	0.95, 1.23	.2358	1.30
Nighttime driving restriction								
≤ 10:00 pm	1.01	0.91, 1.13	.8462	1.01	0.98	0.89, 1.08	.6696	1.21
11:00 pm	0.97	0.83, 1.12	.6530	0.97	0.96	0.84, 1.09	.4971	1.29
12:00 am	0.94	0.81, 1.10	.4543	0.94	0.95	0.84, 1.08	.4426	1.28
1:00 am	0.97	0.85, 1.10	.6272	0.97	0.95	0.84, 1.06	.3298	1.25
Passenger driving restriction								
0 passengers, < 6 months	0.99	0.88, 1.11	.8271	0.99	0.98	0.89, 1.08	.7029	1.22
0 passengers, ≥ 6 months	0.98	0.89, 1.08	.7171	0.98	0.96	0.89, 1.03	.2737	1.16
1 passenger, ≥ 6 months	0.95	0.91, 1.00	.0440*	0.95	0.97	0.93, 1.00	.0511†	1.07
2–3 passengers, ≥ 6 months	1.00	0.94, 1.07	.9950	1.00	0.98	0.93, 1.03	.4263	1.11
Unrestricted license age								
16 years–16, 5 months	1.07	1.01, 1.14	.0333*	1.07	1.05	0.99, 1.11	.1251	1.12
16, 6 months–16, 11 months	1.10	1.00, 1.21	.0470*	1.10	1.07	1.00, 1.13	.0358*	1.13
17 years–17, 5 months	1.07	0.95, 1.20	.2820	1.07	1.05	0.95, 1.16	.3640	1.23
17, 6 months–18 years	1.08	0.97, 1.21	.1523	1.08	1.05	0.96, 1.15	.3214	1.20

Note. Referent levels are shown in prior tables; they are excluded here for brevity. The ratio ratios are adjusted for highway fuel use, other highway-related laws, other GDL core components, state, and state- and age-specific linear trends, seasonality, and unemployment. In the model with adult covariates, the rate ratios are also adjusted for contemporaneous state-specific age 20–24, 25–39, and 60 or older driver fatal crash involvement rates. GDL = Graduated driver licensing. 95% CI = 95% confidence interval for the adjusted rate ratios. CLR = Confidence limit ratio (ratio of upper and lower confidence limits).

*$p < .05$ (reliably estimated). †$p < .10$ (marginally reliably estimated).

APPENDIX B: FIRST JOURNAL ARTICLE

Graduated Driver Licensing and Fatal Crashes Involving 16-19-Year-Olds

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ABSTRACT

Context Graduated driver licensing (GDL) programs were enacted in 43 states from 1996-2007 with the goal of reducing crashes among teen drivers.

Objective To estimate the association of GDL programs with fatal crash involvements among 16-19-year-olds.

Design, Setting, and Participants Pooled cross-sectional time series analysis of quarterly 1986-2007 driver fatal crash incidence for all United States states.

Intervention GDL programs require a mandatory period of supervised driving followed by a period without supervision, but with restrictions on allowed passengers or nighttime driving (stronger programs restrict both, weaker programs restrict only one), prior to full licensure.

Main Outcome Measures Population-based driver fatal crash involvement rates for 16-, 17-, 18-, and 19-year-olds, comparing state-quarters under stronger or weaker GDL programs to state-quarters without GDL.

Results After adjusting for potential confounders, GDL programs were associated with lower driver fatal crash incidence for 16-17-year-olds, but higher incidence for 18-19-year-olds, with an estimated net savings of 437 16-19-year-old fatal crash involvements from 1996-2007. Under stronger GDL programs, fatal crash incidence was 26% lower for 16-year-olds (95% confidence interval [CI], −35%-−16%), 9% lower for 17-year-olds (CI, −17%-1%),

12% higher for 18-year-olds (CI, 1%-23%), and 5% higher for 19-year-olds (CI, −2%-13%). For 16-19-year-olds combined, stronger GDL programs were associated with a net 3% decrease (CI, −8%-3%) in fatal crash incidence.

Conclusion GDL programs are associated with lower driver fatal crash rates among younger teens, but higher rates among older teens. Overall GDL is associated with net crash savings because the reductions among 16-17-year-olds outweigh the increases among 18-19-year-olds. Studies excluding older teens exaggerate the net benefits of GDL.

Graduated Driver Licensing and Fatal Crashes Involving 16-19-Year-Olds

Motor vehicle crashes are the leading cause of death in the United States for teenagers.[1] From 2000-2008, over 23 thousand drivers and 14 thousand passengers 16-19-years-old died.[2] Crash rates are highest among younger teens—the fatal crash rates per mile driven for 16- and 17-year-olds are 150% and 90% greater, respectively, than those for 18- and 19-year-olds.[2,3] The higher crash likelihood of teen drivers is primarily due to lack of driving experience and age-related factors that affect their driving behaviors.[4,5,6,7] Nighttime driving and transporting teen passengers are noteworthy high-risk activities for young drivers.[8,9]

Driver licensing systems in the United States have historically not adequately addressed the need for young novices to gain experience under low-risk conditions before exposing them to the full range of risks associated with unrestricted driving.[10] From 1996-2007, 43 states implemented graduated driver licensing (GDL) programs with the goal of reducing crashes among teen drivers by requiring them to gain substantial on-road experience under conditions of reduced risk before permitting them to drive in riskier conditions.[10,11] GDL programs in the United States allow full, unrestricted licensure for beginning drivers younger than age 18 only after they complete: (a) a learner license period allowing driving only while supervised by an adult, then (b) an intermediate license period allowing unsupervised driving, but with restrictions on nighttime driving, the number of young passengers, or both.[12]

Two of the earliest studies of United States GDL programs, conducted in North Carolina and Michigan, found that GDL was associated with large reductions in 16-year-old driver crashes.[13,14] An editorial accompanying these studies suggested that if GDL reduces crash rates for young teens by delaying licensure, it may also increase crash rates for older teens.[15] This is plausible because teens in the United States can avoid most GDL requirements by delaying licensure until age 18.[16] If younger teens choose to delay licensure until age 18 to avoid GDL requirements, it would increase the proportion of inexperienced 18-19-year-old drivers.[17,18] The editorial called for research to quantify positive and negative effects of GDL on older teen cohorts. Despite the widespread adoption of GDL in the United States, and the fact that numerous studies in several states have confirmed that GDL is associated with reductions in young teen crashes,[19,20] the question of whether GDL simply shifts the crash burden from younger to older teens remains unanswered.

There have been several attempts to conduct multi-state studies of GDL,[21,22,23,24] most of which show similar—though weaker—benefits of GDL compared to single-state studies such as the original studies conducted in North Carolina and Michigan. However, these prior multi-state GDL studies have had several limitations, including methodological problems (e.g., assuming homogenous associations of GDL across all teen ages), inadequate control for potential confounders (e.g., differences in crash rates by state and age), and exclusion of some teen age groups. Most prior studies have failed to examine the net impact of GDL across all teenage drivers. The present study is also a multi-state study of GDL; however it examines how GDL was related to changes in crash incidence for both younger and older teens using an approach that avoids most of the limitations of previous multi-state studies. We estimated how the introduction of GDL was associated with changes in driver fatal crash incidences for 16-, 17-, 18-, and 19-year-olds separately, as well as for 16-19-year-olds combined.

METHODS

Data Sources

Counts of all drivers of passenger cars, light pickup trucks, vans, and sport utility vehicles involved in fatal crashes were obtained from the Fatality Analysis Reporting System for the period 1986-2007.[2] This database provides information on driver characteristics, vehicle characteristics, and crash circumstances for all motor vehicle crashes in the United States that involve a death within 30 days of the incident. Fatal crash involvements were used because no census of non-fatal crashes in the United States exists. The crashes were aggregated by state, driver age (16-, 17-, 18-, or 19-years-old), and quarter (January-March, April-June, July-September, and October-December for each year from 1986-2007). Data for drivers younger than age 16 were excluded because few states allowed unsupervised driving by 15-year-olds[16,25,26,27] and these data were too sparse to permit meaningful analysis.[2] To compute rates, midyear population estimates by state and age were obtained from the United States Census Bureau and quarterly values were interpolated.[28,29,30] Rates using counts of licensed drivers as the denominator were not used because of concerns[12,31,32] about the validity of counts of licensed teen drivers in the only national database where state- and age-specific data exist for all states[33] and also because using driver-based rates underestimates changes in crashes that result from delayed licensure.[17]

The study period of 22 years, multiplied by 4 quarters and 51 states (including the District of Columbia), yields 4488 state-quarters for each teen age group. To classify the quarters according to the type of teen licensing system in effect in each state during each quarter, information on state driver licensing requirements was obtained from archival compilations of licensing requirements.[16,25,26,27] Having a minimum learner permit period, followed by initial nighttime and passenger restrictions during unsupervised driving, are the defining features of GDL programs.[12] Accordingly, these were used as the key elements to categorize quarters into types of teen licensing systems (Table 1). Quarters were coded as having a GDL program if novice 16-year-olds in the state were required to hold a learner permit for at least 3 months, followed by an unsupervised driving period with a nighttime driving restriction starting before 1 AM or a passenger restriction allowing no more than one passenger under age 18. GDL programs that included both of these restrictions were considered stronger than those that had only one. Licensing requirements were considered to be in effect during an entire quarter if they were in place for at least 2 months.

Data Analysis

Four age-specific Poisson regression models were used to estimate separate driver fatal crash involvement rate ratios for 16-, 17-, 18-, and 19-year-olds. These age-specific rate ratios compared quarters under each type of teen licensing system shown in Table 1 to quarters with none of the key GDL elements, adjusted for potential confounders. Because the outcome of interest was population-based rates of driver fatal crash involvements, the natural logarithm of age-specific state population was used as an offset term in the models.[34] Generalized estimating equations with a first-order autoregressive correlation matrix and robust (empirical) variance were used in the models, to account for any correlation among the quarters due to repeated measurements of state age groups over time (geo-demographic clustering).[35] In addition, a combined-age model was used to estimate a single net rate ratio for each type of licensing system combined across 16-19-year-olds. Model fit was assessed using the quasi-likelihood independence model criterion (QIC) and plots of predicted vs. actual crash rates.[36,37]

The regression models included parameters to adjust for confounding resulting from differences in state crash rates (state indicator variables), long-term crash trends (linear time for each state), crash seasonality (quarter indicator variables for each state), state macroeconomic factors (linear quarterly unemployment rate for each state),[38] and crude changes in driving exposure (a linear term to adjust for annual state-specific highway fuel use per capita).[39,40] It has been argued that adjusting for state-specific trends in teen crash rates would remove GDL program effects because these trends may reflect increasingly comprehensive teen driver licensing systems being implemented over time.[24] This should not be a problem in the current study because the long time period examined encompasses many years in which GDL programs were not in effect within each state (1986-1996 or longer) relative to the overall analysis period. This minimizes any effect of GDL programs on the state-specific trend estimates. Linear parameters were also included in the models to represent the separate contemporaneous fatal crash involvement rates of drivers ages 20-24, 25-39, 40-59, and 60-or-older for each state. This was done to control for other unmeasured factors—such as changes in enforcement activity, weather, roadway conditions, and gasoline prices— that might influence teen crash rates. This assumes that GDL does not influence adult crash rates, which is reasonable given that only 7% of adult fatal crashes involve a teenage driver.[2] In addition, indicator variables were included for changes made to the following traffic-safety-related laws: (a) rural interstate speed limits (55, 65, 70, or 75+ miles per hour);[21,41] (b) primary and secondary enforcement seatbelt laws; [21,41] (c) laws making driving with a blood alcohol concentration (BAC) of 0.10 or 0.08 g/dl *per se* illegal;[42] (d) a minimum legal age of 21 for drinking alcohol;[43] (e) zero-tolerance laws making it illegal for persons younger than age 21 to drive with any detectable BAC;[21,41] and (f) immediate administrative license suspension for driving with a BAC that exceeds the legal limit.[44]

To estimate the net population association of GDL programs with fatal crashes for teen drivers, attributable driver fatal crash involvements were calculated using population attributable fractions (for rate ratios ≥ 1) or prevented fractions (for rate ratios < 1) using the age-specific adjusted rate ratios from the models, without regard to their statistical reliability.[45,46] These were used to estimate the actual numbers of increased or decreased driver fatal crashes for each teen age group that are attributable to implementing GDL programs from 1996 through 2007.[45,46] The age-specific attributable crashes were summed to obtain estimates of net changes in 16-19-year-old driver fatal crash involvements associated with implementing GDL programs.

RESULTS

Table 2 displays age-specific and combined 16-19-year-old driver fatal crash involvement rates per 100 000 person-years under each teen licensing system, and rate ratios comparing crash rates under these systems to those during quarters with none of the key GDL elements.

Fatal crash incidences for 16-, 17-, 18-, 19-year-olds and 16-19-year-olds combined were consistently lower when states had three-stage GDL programs, or some of the key GDL elements, than when they had none of these elements. The combined 16-19-year-old unadjusted driver fatal crash rate was 30 per 100 000 person-years under stronger GDL programs, 37 per 100 000 person-years under weaker GDL programs, and 47 per 100 000 person-years with no GDL elements.

In the adjusted models, GDL programs were no longer associated with lower fatal crash incidences for all teen ages. Stronger GDL programs were associated with lower fatal crash incidences for 16- and 17-year-olds, but higher incidences for 18- and 19-year-olds. Compared to time periods with none of the key GDL elements, under stronger GDL programs fatal crash incidences were 26% lower for 16-year-olds (rate ratio [RR], 0.74; 95% confidence interval [CI], 0.65-0.84), 9% lower for 17-year-olds (RR, 0.91; CI , 0.83-1.01), 12% higher for 18-year-olds (RR, 1.12; CI, 1.01-1.23), and 5% higher for 19-year-olds (RR, 1.05; CI, 0.98-1.13). The net association was small, suggesting a 3% decrease in 16-19-year-old combined driver fatal crash incidence under stronger GDL programs (RR, 0.97; CI, 0.92-1.03), relative to having no key GDL elements.

Under weaker GDL programs fatal crash incidences were 16% lower for 16-year-olds (RR, 0.84; CI, 0.75-0.94), 2% lower for 17-year-olds (RR, 0.98; CI, 0.92-1.04), 10% higher for 18-year-olds (RR, 1.10; CI, 1.03-1.18), and not different for 19-year-olds (RR, 1.00; CI, 0.92-1.08). The net association for 16-19-year-olds combined was small, suggesting a 1%

decrease in driver fatal crash incidence under weaker GDL programs (RR, 0.99; CI, 0.95-1.03).

Figure 1 shows age-specific and 16-19-year-old combined estimates of the numbers of driver fatal crash involvements from 1996-2007 attributable to implementing stronger and weaker GDL programs. Each bar in the Figure shows estimates of the numbers of fatal crash involvements prevented (negative values) or added (positive values) by implementing GDL. Since the first program was enacted in 1996, GDL programs (weaker and stronger combined) were estimated to be associated with 1780 fewer driver fatal crash involvements among 16-17-year-olds, but 1343 more involvements among 18-19-year-olds. Although most of the estimated crash savings among 16-17-year-olds was offset by increased crashes among 18-19-year-olds, implementing GDL programs was nonetheless associated with 437 net fewer 16-19-year-old driver fatal crash involvements.

COMMENT

Overall Findings

This article presents the most thorough and rigorous national study of GDL programs to date. We have improved upon prior studies by controlling for potential confounders, addressing the methodological limitations of prior studies, and evaluating the net associations of these programs across the entire 16–19 year old “teenage driver” age spectrum. Our findings suggest that implementing GDL in the United States is associated with decreased driver fatal crash incidences for younger teens—particularly 16-year-olds—but increased incidences for older teens—chiefly 18-year-olds. The age-specific estimates are generally similar to those from a prior multi-state study that adjusted for some state-specific sources of confounding,[23] and they are smaller (for younger teens) or larger (for older teens) than estimates from another study lacking such adjustments.[24]

Although the estimated reductions in fatal crashes among younger teens are largely offset by increases among older teens, GDL is associated with a net reduction in driver fatal crash incidence among 16-19-year-olds combined. While 75% of the crash reduction among younger teens is merely delayed rather than prevented, this delay in incidence is nonetheless a public health benefit for younger teenagers. The largest net reduction is associated with GDL programs that have both nighttime and passenger restrictions during initial unsupervised driving. The net associations found in this study represent several possible crash-reducing influences of GDL including: (a) crude exposure reduction, both fewer young teen drivers and less driving among younger teens who are licensed; (b) reduced risk exposure among teens driving with learner permits and under restricted conditions; and (c) safer driving resulting from improved learning. The net associations also capture possible unintended crash increases among older teens associated with (a) younger teens delaying licensure until age 18 or older to avoid GDL and (b) less experienced 18- and 19-year-old drivers as the result of reduced driving when they were younger.

The reason why GDL programs are associated with larger reductions in fatal crash incidence for 16-year-olds than for 17-year-olds is likely because a greater proportion of 16-year-old's person-time is limited to supervised driving than is the case for 17-year-olds. Most GDL programs have a 6-month learner period and more teens begin driving at age 16, so by age 17 many teens have progressed beyond this maximally protective stage and are into the far less protective intermediate period.[16] Another possibility is that teens who seek licensure at different ages may differ in their driving needs and exposure profiles (i.e., self-selection bias).[47]

The reasons why GDL programs appear to be associated with higher fatal crash incidence for older teens are not known. One likely possibility is that some younger teens delay licensure to avoid GDL requirements (which do not apply beyond age 17 in most states),[16] increasing the proportion of inexperienced drivers among 18-year-olds and, to a lesser extent, among 19-year-olds. Unfortunately, whether GDL is actually associated with delayed licensing nationally cannot be determined because information in the only national database[33] of driver license counts for young teen drivers is inconsistently collected over time and across states.[12,31,32] GDL may also reduce driving experience among younger licensed teens because they may not drive as much with learner permits and under restricted conditions as they would with unrestricted licenses, resulting in their having less experience when they become older teens.

Study Limitations

Results based only on fatal crashes, which represent a small subset of all crashes, may differ from those that would be obtained by examining a broader range of crash severity. The etiology of fatal crashes differs from that of less serious crashes, particularly with regard to high-risk behaviors such as alcohol use and excessive speeding.[48] Unfortunately, no state-specific national database of non-fatal crashes exists for the United States.

The estimates from the present analyses are based on coding the licensing programs under the assumption that all teens pursue unrestricted licensure as early and quickly as possible. This assumption is common and necessary among multi-jurisdiction studies because there is no way to incorporate the complexities of how different age cohorts in different states proceed through different licensing systems at different times into an already highly complex model, even if the data to do so were actually available (they are not). Many teens begin licensing later than the earliest possible age and some spend longer than the minimum required time in the learner and intermediate licensing stages. The effect of this assumption on the estimates is unknown.

The analyses do not directly take into account any “grandfathering” that occurred when GDL programs were being implemented (e.g., allowing teens who applied for a license prior to GDL implementation to avoid some or all program requirements). Moreover, transition effects sometimes result in higher crash rates for a while before and after GDL programs are implemented.[13] Neither the possible transitory effects nor the gradual increases in program effect as greater proportions of licensed teens become subject to all program components were directly modeled. However, the inclusion of long time periods before and after most GDL programs were implemented reduces the influence of these temporary effects on the GDL estimates.

The estimates of association from multi-state studies of GDL are consistently smaller than those typically reported from single-state studies.[19,20] To understand and reconcile these differences, methodologically rigorous time-series analyses of individual state programs are needed that take into account the present findings suggesting that GDL increases crash rates for older teens. Single-state studies of GDL can avoid some of the limitations of multi-state studies by including less-severe crashes, incorporating how teens actually progress through the GDL program, taking grandfathering and transition effects into account, and better controlling for state-specific factors.[49] To fully estimate the effect of GDL on teen crashes, single-state studies need to examine crashes for all ages from 16 through 19, not merely for 16- or 17-year-olds. Examining only young teen crashes exaggerates the protective value of GDL by focusing only on drivers who are largely sheltered during the learner and intermediate licensing stages, overlooking the potential negative effect of producing less-experienced older teenage drivers.

Implications for Practice

Clinicians should support upgrading their states' GDL programs to include appropriately protective restrictions on both nighttime driving and transporting teen passengers when teens begin driving unsupervised. They should also consider advising parents to encourage their teens to begin the licensing process before age 18 so the parents can play an active role in their child's learning to drive. Parents should be encouraged to implement a "family GDL program," providing extensive supervised practice driving in widely varying conditions for 6-12 months and then ensure their child does not drive after 9 PM or carry more than one young passenger for at least 6 months when they begin driving unsupervised.

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Study concept and design: Masten, Foss, Marshall.

Acquisition of data: Masten, Foss.

Analysis and interpretation of data: Masten, Foss, Marshall.

Drafting of the manuscript: Masten, Foss, Marshall.

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FIGURE LEGEND

Figure 1. Estimated Driver Fatal Crash Involvements Attributable to Graduated Driver Licensing (GDL) by Individual Year of Age and for 16-19-year-olds Combined, United States 1996-2007 [Negative values represent fatal crash involvements prevented by GDL].

Table 1. Teen Driver Licensing System Characteristics, Number of Quarters for each Age Group in each Category, and Number of Unique States Contributing at Least One Quarter to each Category, United States 1986-2007

Driver licensing system characteristics	GDL system*	Quarters†	Unique states
		No. (%)	**No. (%)‡**
No mandatory learner permit holding period or initial license restrictions	No	1989 (44.3)	39 (76.5)
Mandatory learner permit holding period, but no initial license restrictions	No	1013 (22.6)	25 (49.0)
Initial license restrictions, but no mandatory learner permit holding period	No	448 (10.0)	10 (19.6)
GDL with one license restriction during unsupervised driving§	Weaker	578 (12.9)	24 (47.0)
GDL with two license restrictions during unsupervised driving**	Stronger	460 (10.2)	26 (51.0)

*GDL indicates graduated driver licensing.
†There are 4488 quarters per teen age group for a grand total of 17 952 quarters.
‡The counts add to greater than 51 because some states changed driver licensing systems over time.
§Mandatory learner permit holding period and either a nighttime (79% of quarters) or passenger (21%) restriction during initial unsupervised driving.
**Mandatory learner permit holding period and both nighttime and passenger restrictions during initial unsupervised driving.

Table 2. Driver Fatal Crash Involvements, Unadjusted Crash Rates per 100 000 Person-years, Unadjusted and Adjusted Rate Ratios for Different Teen Driver Licensing Systems by Individual Year of Age and for 16-19-year-olds Combined, United States 1986-2007

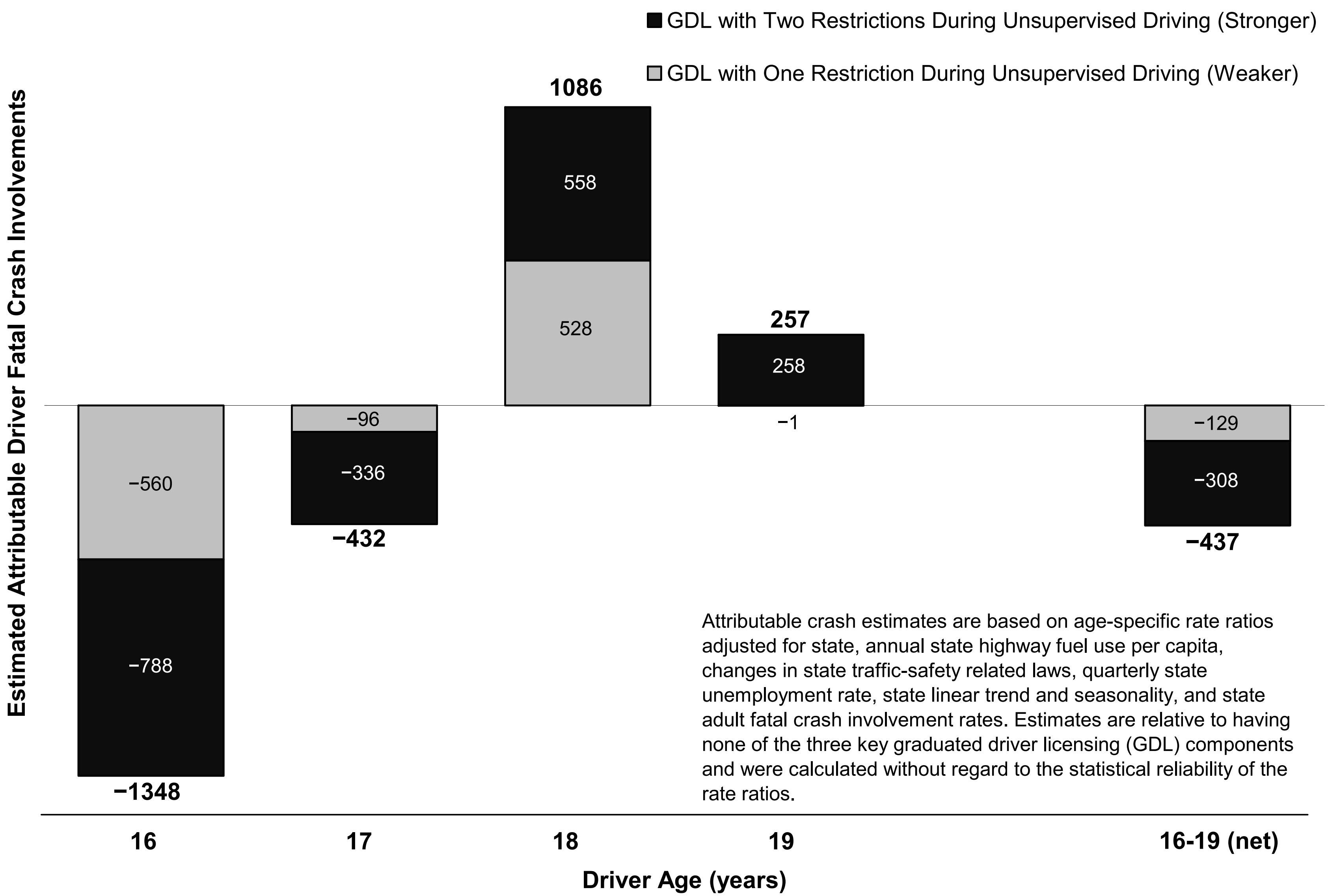
Age group Driver licensing system characteristics	GDL system*	Driver fatal crashes	Person-years	Crash rate per 100 000 person-years	Unadjusted rate ratio	Adjusted rate ratio (95% CI)†
16-19-year-olds (combined)						
All driver licensing systems		131 604	338 951 628	38.8		
No learner permit holding period or initial restrictions	No	52 952	112 195 675	47.2	1.0	1.0 (ref)
Learner permit holding period, but no initial restrictions	No	27 702	68 574 136	40.4	0.86	0.99 (0.94-1.03)
Initial restrictions, but no learner permit holding period	No	15 680	51 599 192	30.4	0.64	1.01 (0.94-1.10)
GDL with one restriction during unsupervised driving	Weaker	18 711	50 909 631	36.8	0.78	0.99 (0.95-1.03)
GDL with two restrictions during unsupervised driving	Stronger	16 559	55 672 995	29.7	0.63	0.97 (0.92-1.03)
16-year-olds						
All driver licensing systems		23 677	84 030 933	28.2		
No learner permit holding period or initial restrictions	No	10 306	27 648 385	37.3	1.0	1.0 (ref)
Learner permit holding period, but no initial restrictions	No	5252	16 991 656	30.9	0.83	0.94 (0.83-1.07)
Initial restrictions, but no learner permit holding period	No	2676	12 605 188	21.2	0.57	1.04 (0.86-1.27)
GDL with one restriction during unsupervised driving	Weaker	3082	12 791 304	24.1	0.65	0.84 (0.75-0.94)
GDL with two restrictions during unsupervised driving	Stronger	2361	13 994 400	16.9	0.45	0.74 (0.65-0.84)
17-year-olds						
All driver licensing systems		31 261	84 803 766	36.9		
No learner permit holding period or initial restrictions	No	12 749	28 081 827	45.4	1.0	1.0 (ref)
Learner permit holding period, but no initial restrictions	No	6476	17 211 198	37.6	0.83	0.93 (0.85-1.00)
Initial restrictions, but no learner permit holding period	No	3828	12 840 368	29.8	0.66	0.95 (0.85-1.06)
GDL with one restriction during unsupervised driving	Weaker	4516	12 724 135	35.5	0.78	0.98 (0.92-1.04)
GDL with two restrictions during unsupervised driving	Stronger	3692	13 946 239	26.5	0.58	0.91 (0.83-1.01)
18-year-olds						
All driver licensing systems		38 631	83 683 087	46.2		
No learner permit holding period or initial restrictions	No	14 994	27 540 374	54.4	1.0	1.0 (ref)
Learner permit holding period, but no initial restrictions	No	8029	16 796 916	47.8	0.88	1.05 (0.98-1.13)
Initial restrictions, but no learner permit holding period	No	4637	12 749 647	36.4	0.67	1.06 (0.92-1.21)
GDL with one restriction during unsupervised driving	Weaker	5607	12 703 182	44.1	0.81	1.10 (1.03-1.18)
GDL with two restrictions during unsupervised driving	Stronger	5364	13 892 969	38.6	0.71	1.12 (1.01-1.23)

Table 2 (Continued)

Age group Driver licensing system characteristics	GDL system*	Driver fatal crashes	Person-years	Crash rate per 100 000 person-years	Unadjusted rate ratio	Adjusted rate ratio (95% CI)†
19-year-olds						
All driver licensing systems		38 035	86 433 842	44.0		
No learner permit holding period or initial restrictions	No	14 903	28 925 089	51.5	1.0	1.0 (ref)
Learner permit holding period, but no initial restrictions	No	7945	17 574 366	45.2	0.88	1.02 (0.94-1.10)
Initial restrictions, but no learner permit holding period	No	4539	13 403 989	33.9	0.66	1.01 (0.90-1.15)
GDL with one restriction during unsupervised driving	Weaker	5506	12 691 011	43.4	0.84	1.00 (0.92-1.08)
GDL with two restrictions during unsupervised driving	Stronger	5142	13 839 387	37.2	0.72	1.05 (0.98-1.13)

*GDL indicates graduated driver licensing, which includes both a mandatory learner permit holding period and an unsupervised driving stage with one (weaker) or two (stronger) initial license restrictions.

†Adjusted for state, annual state highway fuel use per capita, changes in state traffic-safety-related laws (e.g., seat belt laws), quarterly state unemployment rate, state linear trend and seasonality, and state contemporaneous age 20-24, 25-39, 40-59, and 60-or-older driver fatal crash involvement rates. CI indicates confidence interval.


GDL with Two Restrictions During Unsupervised Driving (Stronger)
GDL with One Restriction During Unsupervised Driving (Weaker)
Estimated Attributable Driver Fatal Crash Involvements
Driver Age (years)
16
17
18
19
16-19 (net)
−560
−788
−1348
−96
−336
−432
1086
558
528
257
258
−1
−129
−308
−437
Attributable crash estimates are based on age-specific rate ratios adjusted for state, annual state highway fuel use per capita, changes in state traffic-safety related laws, quarterly state unemployment rate, state linear trend and seasonality, and state adult fatal crash involvement rates. Estimates are relative to having none of the three key graduated driver licensing (GDL) components and were calculated without regard to the statistical reliability of the rate ratios.

APPENDIX C: SECOND JOURNAL ARTICLE

National Study of Graduated Driver Licensing Program Component Calibrations

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Graduated driver licensing (GDL) programs are specialized licensing systems for beginner drivers adopted in all U.S. states to reduce young teen drivers' exposures to high-risk driving situations while they gain driving experience. Although several studies document the success of GDL programs overall in reducing young teen crash rates, little is known about which specific components of these programs (e.g., nighttime driving restrictions) and, especially, which calibrations of these components (e.g., 10 PM, 11 PM, 12 AM, or 1 AM), are associated with the largest crash reductions. The goal of this study was to identify which component calibrations are associated with the largest reductions in fatal crash involvements for 16–17-year-olds. Driver fatal crash involvements for all U.S. states from 1986–2007 were analyzed using Poisson regression models to estimate the associations of various GDL component calibrations with 16- and 17-year-old driver fatal crash incidence, after adjusting for potential confounders. There is clear evidence indicating that (a) a minimum learner permit holding period of 9–12 months and (b) a passenger restriction allowing only one teen passenger for 6 months or longer are the calibrations for these components associated with the largest reductions in 16-17-year-old driver fatal crash involvements. There is less clear evidence suggesting that (a) disallowing learner driving until age 16, (b) disallowing intermediate licensure until age 16½ to 17, and (c) a nighttime driving restriction starting at 10 PM or earlier are the calibrations for these components associated with the largest reductions in 16-17-year-old driver fatal crashes. There was no clear evidence to support particular calibrations for supervised driving hours or unrestricted license ages.

Keywords: graduated driver licensing; GDL; teen drivers

National Study of Graduated Driver Licensing Program Component Calibrations

1. Introduction

Graduated Driver Licensing (GDL) was designed with that understanding that it takes a long time to learn complex tasks, that learners make more errors early in the learning process and that improvement (i.e., a decrease in errors) can be described as a power function of experience (Anderson, 1994; Anderson, Fincham, & Douglass, 1999; Waller, 2003). GDL provides the practical experience needed to move novice learner drivers along their learning curves, while minimizing their risk of crashing (Foss & Goodwin, 2003; Waller, 2003). To do this GDL systems include three different stages of licensure beginning with a mandatory minimum learner permit period during which driving is only allowed under the supervision of an experienced adult driver. This allows accumulation of experience with minimal crash risk. An intermediate period allowing unsupervised driving follows, during which exposure to high risk conditions is limited by restrictions on the number of passengers and nighttime driving. This is meant to provide an opportunity to learn things that are not possible with an adult present (e.g., self-control, driving alone) in somewhat less risky driving conditions. A final license stage allows unrestricted driving, finally exposing novices to the full range of driving risks (Foss, 2007). As novice drivers systematically move through these stages, accumulating experience that moves them along their learning curves, the restrictions that are designed to limit their exposure to risky driving conditions are gradually removed.

Although the defining feature of GDL is three distinct licensing stages (i.e., learner, intermediate, and full), there are four components of GDL programs: (a) learner permit minimum holding time period, (b) number of supervised driving hours required during the learner period, (c) intermediate licensing stage nighttime driving restriction, and (d) intermediate stage passenger restriction (Insurance Institute for Highway Safety [IIHS], 2011). In addition, there are three age-based components of teen licensing systems: (a) learner stage minimum entry age, (b) intermediate stage minimum age, and (c) unrestricted licensure minimum age. Various combinations of these seven GDL and age-based components and differences in how they are applied (i.e., calibrated) vary over time and between U.S. states.

Beginning in 1996, all 50 U.S. states and the District of Columbia eventually adopted three-stage GDL systems. Numerous single-state studies have found GDL to be associated with crash reductions of 20–40% among younger teens (Shope, 2007; Shope & Molnar, 2003). However, single-state studies are unable (by their nature) to address which calibrations of components are specifically associated with reduced crashes. Three multi-state studies have attempted to address this issue (Chen et al., 2006; McCartt et al., 2010; Vanlaar, et al., 2009), but none examined all four GDL components along with all three age-based components. Moreover, the Chen et al. (2006) and McCartt et al. (2010) studies included little or no adjustment for state-specific sources of confounding and Vanlaar et al's (2009) models resulted in suspiciously high parameter estimates that imply misspecification (e.g., thousand-fold increases in relative fatal crash rates for minor exceptions to component calibrations).

The present study built upon these prior studies taking advantage of a multi-state approach, but includes all seven GDL and age-based components, a longer pre-GDL time period, and additional state-specific controls for sources of confounding (e.g., trends and changes to other traffic safety laws). The goal was to identify which component calibrations are associated with the largest reductions in 16- and 17-year-old driver fatal crash involvements. Although it is sometimes assumed that more restrictive calibrations (e.g., allowing no young passengers rather than one) produce larger crash reductions, this is not necessarily the case. If components are calibrated too restrictively, compliance may suffer to the extent that the benefit is attenuated or completely lost (Goodwin & Foss, 2004; Goodwin et al., 2006). The intent of the present analysis was not to determine the combinations of components that represent an optimal GDL system. The observational nature of the existing data makes it exceedingly difficult to compare components, since many states have introduced similar GDL systems that include similar combinations of components.

2. Methods

2.1 Data Sources

Counts of all drivers of passenger cars, light pickup trucks, vans, and sport utility vehicles involved in fatal crashes were obtained from the Fatality Analysis Reporting System for the period 1986-2007 (NHTSA, 2010). This database includes information on driver characteristics, vehicle characteristics, and crash circumstances for all motor vehicle crashes in the U.S. that result in a death within 30 days of the incident. Data were aggregated by state, driver age (16- or 17-years-old), and quarter (January-March, April-June, July-September, and October-December) for each year from 1986–2007.

To compute rates, midyear population estimates by state and age were obtained from the United States Census Bureau (2010a, 2010b, 2010c) then quarterly values were interpolated. Crash rates per licensed driver were not used because they underestimate changes in crashes that result from reduced licensure, so their use would result in inappropriate effect estimates for components that achieve crash savings by reducing licensure (McKnight et al., 2002). Additionally, driver-based rates were not used because of concerns about the validity of teen driver license counts in the only national database where state- and age-specific data exist for all states (Ferguson et al., 2007; Foss, 2007; IIHS, 2006).

2.2 Coding of Component Calibrations

For each age group analyzed there were 4,488 quarters, representing 22 years × 4 quarters × 50 states and the District of Columbia (Table 1). Coding was based on historical information about state driver licensing requirements obtained from archival compilations of licensing laws (American Association of Motor Vehicle Administrators, 1999; American Automobile Association Foundation for Traffic Safety, 2007; Federal Highway Administration [FHWA], 1984, 1986, 1988, 1990, 1992, 1994, 1996; IIHS, 2011). The calibrations coded for each component were initially more specific, but to reduce the likelihood that estimates would be confounded by state, calibrations were collapsed into those shown in the table so that each category included data for at least one quarter from at least five different states.

Nighttime and passenger restrictions were only coded as being in effect if they applied specifically to 16- or 17-year-olds with a license to drive unsupervised. The restriction calibrations were different for 16-year-olds and 17-year-olds for 8.9% of quarters for nighttime restrictions and 1.3% of quarters for passenger restrictions. In addition, some restrictions had multiple stages (e.g., no passengers for the first 6 months of intermediate licensure, and no more than one passenger for the second 6 months). To maintain consistency in how restrictions were coded, the first-occurring phases of multi-phase restrictions as they applied to 16-year-olds were used for both age groups. The effect of this misclassification on the 17-year-old rate ratios would be minimal because the calibrations only differed between the age groups for a small percentage of quarters. "Passenger restrictions" were disregarded if they only limited the number of passengers to the number of seats or seat belts available in the vehicle or if they only applied during times when the teens were already forbidden from driving due to nighttime driving restrictions. A component calibration was considered to be in effect during an entire quarter if it was implemented for at least 2 months.

2.3 Analysis Approach

Age-specific Poisson regression models were used to estimate driver fatal crash involvement rate ratios separately for 16- and 17-year-olds. The models simultaneously include the ranges of calibrations for all seven GDL and age-based components. These component calibrations were parameterized using indicator variables, allowing us to estimate age-specific rate ratios comparing quarters under each component calibration to quarters without that component, adjusted for a variety of potential confounders. The natural log of age-specific state population was used as an offset term in the models, resulting in analyses of population-based driver fatal crash involvement rates (McCullagh & Nelder, 1989). Generalized estimating equations with a first-order autoregressive working correlation matrix and robust (empirical) variance estimates were used to account for any correlation among the quarters due to repeated measurements of state age groups over time (Liang & Zeger, 1986). In addition to the two age-specific models, a combined-age model was used to estimate a single net rate ratio for each component calibration combined across 16–17-year-olds.

The Poisson models included parameters to adjust for confounding resulting from overall differences in state crash rates (state indicator variables), long-term crash trends (linear time for each state), crash seasonality (quarter indicator variables for each state), state macroeconomic factors (quarterly unemployment rate for each state; Bureau of Labor Statistics, 2010), and crude changes in driving exposure (annual state-specific highway fuel use per capita; FHWA, 1996, 1997a, 1997b, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2006, 2008). The long time period examined encompasses many years in which GDL programs were not in effect within each state (1986–1996 or longer) relative to the overall analysis period. This long pre-GDL period was intended to minimize possible bias in the state-specific trend estimates due to the proliferation of GDL after 1998. Linear parameters were also included in the regressions to separately model the contemporaneous fatal crash involvement rates of drivers ages 20–24, 25–39, 40–59, and 60-or-older for each state. This was done to control for other unmeasured factors—such as varying weather and roadway conditions and changes in enforcement levels—that might affect teen driver crash rates. This assumes that GDL does not influence adult crash rates, which is reasonable given that only 3% of adult fatal crashes involve a 16-17-year-old driver (NHTSA, 2010). In addition, indicator variables were included for changes made to the following: (a) rural interstate speed limits (55, 65, 70, or 75+ miles per hour; (b) primary and secondary enforcement seatbelt laws; (c) laws making driving with a blood alcohol concentration (BAC) of 0.10 or 0.08 g/dl *per se* illegal; (d) a minimum legal age of 21 for drinking alcohol; (e) "zero-tolerance" laws making it illegal for persons younger than age 21 to drive with any detectable BAC; and (f) immediate administrative license suspension for drivers with a BAC that exceeds the legal limit (Dee et al., 2005; Freeman, 2007; Lovenheim & Slemrod, 2010; Wagenaar & Maldonado-Molina, 2007; Wagenaar et al., 2007).

3. Results

Table 2 displays age-specific and combined 16-17-year-old driver fatal crash involvement rates per 100,000 person-years under each component calibration. Table 3 shows rate ratios comparing fatal crash rates under each calibration to the rate during quarters with the referent calibration for each component (typically, this is the absence of the component) after efforts to remove the various sources of confounding. The factors accounting for most of the changes between the crude and adjusted rate ratios were adjustments made for overall differences in state fatal crash rates (i.e., state indicator variables) and those for state-specific trends and seasonality. The age-specific and 16-17-year-old combined findings for each component are discussed in the following subsections.

3.1 Learner Stage Minimum Entry Ages

Requiring beginning drivers to be age 15 or older to start learner driving was not reliably associated with meaningful differences in fatal crash incidence for either age group, nor for 16-17-year-olds combined.

3.2 Learner Permit Minimum Holding Periods

Requiring learner permits to be held for up to 4 months was not reliably associated with differences in fatal crash incidence for either age group. Learner permit lengths of 5–6 months were associated with 11% lower incidence for 16-year-olds, 9% lower incidence for 17-year-olds, and 9% lower incidence for 16-17-year-olds combined. Learner permit lengths of 9–12 months were associated with 26% lower incidence for 16-year-olds, 17% lower incidence for 17-year-olds, and 21% lower incidence for 16-17-year-olds combined.

3.3 Supervised Driving Hours Requirements

Requiring a specified number of hours of supervised driving was not reliably associated with lower fatal crash incidence for either age group. Requiring 40 hours of supervised driving—which is the most common calibration—was actually associated with 14% higher incidence for 16-year-olds, 13% higher incidence for 17-year-olds, and 14% higher incidence for 16-17-year-olds combined.

3.4 Intermediate License Stage Minimum Ages

Intermediate licensing stage beginning ages starting younger than 16 years were associated with 29% higher fatal crash incidence and minimum ages of 16 years to 16, 5 months were associated with 18% higher incidence for 16-year-olds. By comparison, intermediate licensing stages beginning at ages from 16, 6 months to 17 years were associated with 23% lower incidence for 16-year-olds. None of the intermediate stage licensing age calibrations were associated with meaningful differences in incidence for 17-year-olds or 16-17-year-olds combined.

3.5 Nighttime Driving Restrictions

Nighttime driving restrictions starting at 10 PM or earlier were associated with 19% lower 16-year-old fatal crash incidence. None of the other nighttime driving restriction calibrations were associated with meaningful differences in incidence for 16-year-olds, and none of the calibrations were associated with meaningful differences in incidence for 17-year-olds or 16-17-year-olds combined.

3.6 Passenger Restrictions

Fatal crash incidence was 20% lower for 16-year-olds, 12% lower for 17-year-olds, and 15% lower for 16-17-year-olds combined under restrictions limiting them to one teen passenger for at least 6 months or longer. None of the other passenger restriction calibrations were associated with meaningful differences in fatal crash incidence for either of the age groups or 16-17-year-olds combined.

3.7 Unrestricted License Minimum Age

Granting unrestricted licensure at any age 16 years or older was associated—in most cases reliably—with lower fatal crash incidence for 16-year-olds (ranging from 11% to 26% lower), but higher incidence for 17-year-olds (ranging from 25% to 53% higher). No unrestricted licensing age calibration was associated with a reliable difference in fatal crash incidence for 16–17-year-olds combined.

4. Discussion

The goal of this study was to identify which component calibrations are associated with the largest reductions in 16-17-year-old driver fatal crash involvements. Our conclusions are summarized in Table 4. The level of support for these calibrations was deemed to be "clear" if:

1. The calibration rate ratio point estimates suggested 10% or larger decreases in incidence for both 16-year-olds and 17-year-olds, or a 10% or larger decrease for 16-17-year-olds combined;
2. The calibration rate ratio point estimates meeting the first criterion were at least 10 percentage-points lower than for the other calibrations; and
3. For calibrations meeting the first two criteria, none of the rate ratio point estimates were consistent with a 10% or larger increase in incidence for either age group or 16-17-year-olds combined.

The level of support for a particular calibration was deemed to be "less clear" if these criteria were met for only one of the age groups. The criteria were applied without regard to the level of statistical reliability of the rate ratios. For learner permit holding periods and passenger restrictions there was clear evidence to support particular calibrations. For learner stage entry ages, intermediate license stage ages, and nighttime driving restrictions there was less clear evidence to support particular calibrations. For supervised driving hours and unrestricted license ages there was no clear evidence to support a particular calibration. We caution that these findings are necessarily limited to calibrations that have actually been implemented.

Other untried calibrations might prove to be better yet. Also, while these identify calibrations of individual components most clearly associated with reductions in fatal crash involvement, they do not indicate how the components interact or how they are associated with non-fatal crashes. Therefore, although it seems reasonable to do so, combining these individual calibrations may not create an "optimum" GDL program.

4.1 Implications

Prior studies of GDL and age-based licensing system component calibrations have had methodological limitations, such as failing to adequately control for potential confounders, using overly-broad categorizations of calibrations (e.g., any nighttime driving restriction vs. none), or constraining calibrations to fit a linear pattern, which only permits monotonic increases or decreases across calibrations (Chen et al., 2006; McCartt et al., 2010; Vanlaar, et al., 2009). Because of differences in how component calibrations were parameterized and confounding was controlled, it is difficult to meaningfully compare the findings from the current study to those from prior multi-state studies. Where comparisons can be made, the present findings differ substantially from those of prior studies. Findings from earlier studies differ from one another as well (Chen et al., 2006; McCartt et al., 2010; Vanlaar, et al., 2009). The findings here—like those of previous studies—represent parameter estimates from statistical models fitted to observational data. This fact, along with the absence of data on person- or family-level confounders associated with driving styles and decisions about beginning to drive, suggest that the findings should be interpreted with care.

4.1.1 Learner Stage Minimum Entry Ages

Because all states had minimum learner ages throughout the entire study time period, the findings for this age-based component reflect long-term patterns across all states. Although none of the calibrations were reliably associated with lower incidence, the rate ratios for delaying learner driving until age 16 years suggest that this calibration has the most potential for fatal crash reduction, particularly for 16-year-olds. That 16-year-olds may have fewer fatal crashes when they are allowed to drive only on a learner permit with a supervising adult for half or more of the year is unremarkable. McCartt et al. (2010) found older learner stage entry ages to be associated with lower incidence for 16-year-olds, but not for 17-year-olds. Given the wide confidence intervals and lack of statistical reliability, our results at best provide only suggestive evidence to support a learner age of 16 years.

4.1.2 Learner Permit Minimum Holding Periods

Requiring learner permits to be held for minimum amounts of time was supported by the findings, as long as they had to be held for a minimum of 5 months. Although those lasting 5–6 months were associated with reduced incidence of fatal crash involvement, 9–12 month holding periods were associated with substantially greater reductions. Learner permit holding periods may reduce crashes through three non-exclusive mechanisms: (a) minimizing crash risk during initial driving through the presence of an adult supervisor, who is a co-driver and whose presence also discourages otherwise impulsive adolescent behaviors, (b) increasing driving skill by encouraging more practice under controlled conditions, and (c) reducing the amount of driving by novices during their initial months with a license. Compliance with learner permit holding periods is ensured because licensing agencies, not merely individual drivers, must follow these dictates. In view of the dramatically lower crash rates among supervised drivers (e.g., Mayhew et al., 2003), it is curious that none of the prior multi-state GDL studies found unique crash reductions associated with the duration of learner periods. This may be explained by a serendipitous finding of the present study (not reported above) that failing to adjust for overall differences in fatal crash rates between states along with state-specific trends results in an apparent lack of association between prescribed learner permit duration and fatal crash incidence.

4.1.3 Supervised Driving Hours Requirements

Minimum supervised driving hours requirements are an attempt to ensure that learner periods achieve what they should—sufficient driving practice—rather than simply assuming that driving practice will occur naturally during the required learner permit holding period. The findings suggest that requirements for minimum supervised driving hours are not reliably associated with lower driver fatal crash incidence for either age group. This GDL component does not appear to produce the intended result—encouraging novices to obtain a sufficient amount of driving experience to materially reduce their fatal crash risk. Given that there is no evidence that any specific amount of supervised driving less than 118 hours (Gregersen, et al., 2000) is reliably associated with decreased crash risk, this is not surprising. Moreover, requiring a certain number of supervised hours is somewhat redundant with requiring a minimum learner period length. Novices teen may accumulate more than the minimum required number of hours without the mandates. Recent evidence also suggests that states have not effectively informed parents about these requirements (O'Brien et al., 2011). Overall the preponderance of evidence suggests that simply not requiring any minimum number of supervised driving hours is as effective as requiring any particular number.

4.1.4 Intermediate License Stage Minimum Ages

Allowing teens to begin intermediate stage driving between 16½ and 17 years of age was the only calibration associated with fatal crash reductions among 16-year-olds; no calibration was associated with lower incidence among 17-year-olds. That 16-year-olds have fewer fatal crashes when they are only allowed to drive unsupervised for half of their 16th year is unsurprising. These findings are consistent with those of McCartt et al. (2010), which suggested that older unsupervised licensing ages (intermediate and full mixed) were associated with lower incidence for 16-year-olds, but not for 17-year-olds. Given that there can only be a minimum intermediate license age when an intermediate license stage exists, and having an intermediate licensing stage was defined as having a nighttime or passenger driving restriction—two other GDL components—there was concern that our results for minimum intermediate licensing age might have been affected by multicollinearity. However, excluding this component from analyses produced few changes in the parameter estimates for the remaining components, suggesting that multicollinearity was not a significant issue.

4.1.5 Nighttime Driving Restrictions

In principle, it would seem that earlier nighttime driving restriction start times should be associated with the largest net crash reductions because they target a larger proportion of actual teen driving exposure. This was the case for 16-year-olds, though there was no dose-response relationship as would be expected. Only nighttime driving restrictions starting at 10 PM or earlier were reliably associated with lower fatal crash incidence. No start times were reliably associated with changes in 17-year-old incidence. This seems reasonable as night driving limits would be expected to apply to a higher proportion of 16-year-olds than 17-year-olds, either by statute or by default, because some proportion of 17-year-olds would already have completed their restriction requirement while they were 16 years old. Although our conclusion regarding 16-year-olds is consistent with McCartt et al.'s (2010) findings that earlier restriction start times result in fewer fatal crashes, the present results differ in that they suggest no benefit of nighttime driving restrictions with later start times. This difference in findings is likely due in part to the fact that our estimates here were not constrained to fit a linear pattern. Our results also differ in that we did not find any nighttime restriction start times to be associated with reduced 17-year-old incidence.

4.1.6 Passenger Restrictions

The findings for passenger restrictions shed some light on the long-standing question of whether a more restrictive limit (no passengers) that will likely meet with less compliance is more beneficial than a less restrictive limit (one passenger) with which compliance will be greater. Passenger restrictions allowing no more than one teen passenger for 6 months or longer were associated with a greater reduction in fatal crash involvement than complete bans on teen passengers for both 16- and 17-year-olds. This conflicts directly with findings reported by McCartt et al. (2010), which suggested that only passenger restrictions allowing zero passengers are associated with lower driver fatal crash incidence among 16- and 17-year-olds. This was the only component in their study that was not constrained to fit a linear pattern, so differences in parameterization strategies cannot account for the divergence in findings. It seems likely that the differences are due to more direct control for state-specific sources of confounding used in our study. Because young teen drivers tend to carry more passengers than other age groups—which increases their chances of being involved in a fatal crash because there are more people per crash who could potentially die—the use of driver fatal crash involvement data in both studies potentially confuses the interpretation of the passenger restriction associations. Whereas the associations for the other components can generally be thought of as reducing crashes, passenger restrictions may have simply reduced the number of passengers killed in crashes (or the number of crashes, or both). Nonetheless, this would still be a benefit of passenger restrictions.

4.1.7 Unrestricted License Minimum Age

All states had minimum unrestricted licensing ages throughout the entire study period, so again the results for this age-based component reflect long-term patterns in teen fatal crash rates both before and after GDL came into being. Granting unrestricted licensure at any age from 16 to 18 years was generally associated with lower fatal crash incidence for 16-year-olds, but higher incidence for 17-year-olds, relative to granting unrestricted licensure at age 15 years. No calibrations were associated with a decrease in incidence for 16-17-year-olds combined. We found no calibration for which there is a decrease in 16-year-old incidence without a concomitant increase in 17-year-old incidence. Overall the findings do not provide clear evidence that there is an unrestricted license age calibration that is preferable to the others for reducing driver fatal crash incidence among 16-17-year-olds.

4.2 Limitations

The analyses here were necessarily confined to fatal crashes. The contributing factors in fatal crashes are known to differ from those in less-severe crashes, particularly with regard to high-risk behaviors such as alcohol use and excessive speeding (Lam, 2003). GDL programs are designed to reduce crashes that result from lack of driving savvy, rather than deliberate risk taking behaviors (Waller, 2003). Hence GDL is inherently less capable of influencing factors having to do with behaviors that are more common in fatal crashes (e.g., excessive speeding, drink-driving) than young driver crashes generally, which tend to reflect inexperience rather than deliberate risk-taking or over-confidence (McKnight & McKnight, 2003). Consequently, the extent to which the results here are generalizable to less-severe crashes is unknown.

This study did not include personal- or family-level covariates associated with driving style or decisions about when to begin driving. It is possible that had they been available these might have helped explain some of the findings. Teens who voluntarily delay licensure may have quite different crash risks from those who pursue early licensing.

Some teen licensing system components, such as intermediate stage driving restrictions following a 12-month learner period, would not be expected to fully influence an entire age cohort of teen drivers until a year or more after the date they are implemented. Hence, the full influence of these components would have been realized gradually as increasing proportions of teens became subject to them. The gradual increases in effect as greater proportions of licensed teens become subject to these components were not directly modeled because the practical difficulty of estimating the time and rate at which several hundred provisions would have gradually reached their full potential effect was prohibitive. However, the long time periods analyzed both before and after most GDL programs and components were implemented were intended to smooth out these temporary effects so that the long-term averages would converge towards true values even with these temporary and delayed effects present.

The rate ratios for the calibrations do not address how the components interact with each other. Thus the results do not address, for example, whether an 11 PM nighttime driving restriction might have a different effect when combined with a zero-passenger limit than it would with a one-passenger limit. GDL components probably do interact, but the large number of possible combinations of component calibrations, along with an insufficient number of cases (state quarters), prohibited analysis of how they interact. Empirical studies are necessarily limited to the combinations and calibrations that have at some point actually been implemented. The data simply do not exist to extract answers to questions like "Which GDL component is most important?" and "What's the ideal combination of components to reduce crashes?" There is also the higher-order issue that a simple empirical analysis, lacking a guiding conceptual structure, cannot answer "Which component has the biggest effect?" This is because the components share variance and decisions have to be made regarding which component is assigned that shared variance, a decision that must rest on conceptual rather than empirical grounds. Hence, although the results of this study do provide information from real-world programs that operate in different contexts about how calibrations of individual components are related to fatal crash involvement, they do not necessarily suggest how to calibrate an optimum GDL program.

4.3 Conclusions

There is clear evidence indicating that (a) a minimum learner permit holding period of 9–12 months and (b) a passenger restriction allowing only one teen passenger for 6 months or longer are the calibrations for these components associated with the largest reductions in 16-17-year-old driver fatal crash involvements. There is less clear evidence suggesting that (a) disallowing learner driving until age 16, (b) disallowing intermediate licensure until age 16½ to 17, and (c) a nighttime driving restriction starting at 10 PM or earlier are the calibrations for these components associated with the largest reductions in 16-17-year-old driver fatal crashes. There was no clear evidence to support particular calibrations for supervised driving hours or unrestricted license ages. We caution that the results of this study merely identify calibrations of individual components most clearly associated with reductions in fatal crash involvement. They do not incorporate how the components interact, nor do they address the vast majority of teen crashes that do not involve a fatality. Therefore, although it seems reasonable to do so, combining these individual calibrations may not create an "optimum" GDL program.

5. Highlights

- This study provides clear evidence that the calibrations for learner permit holding periods and passenger restrictions associated with the largest reductions in 16-17-year-old driver fatal crashes are:

    - Learner permit holding periods of 9–12 months

    - Passenger restrictions allowing only one teen passenger for 6 months or longer

6. Acknowledgement

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Table 1. Teen Licensing System Component Calibrations, Number of Quarters for each Age Group in each Calibration, and Number of Unique States Contributing at Least one Quarter to each Calibration, United States 1986–2007

Component Calibration	Quarters‡ No. (%)	Unique states No. (%)§
Learner stage entry age		
< 15 years	747 (16.6)	9 (17.6)
15 years–15, 5 months	2,050 (45.7)	28 (54.9)
15, 6 months–15, 11 months	854 (19.0)	14 (27.4)
16 years	837 (18.6)	14 (27.4)
Learner permit holding period		
None	2,330 (51.9)	44 (86.3)
< 3 months	466 (10.4)	10 (19.6)
3–4 months	442 (9.8)	13 (25.4)
5–6 months	1,069 (23.8)	42 (82.3)
9–12 months	181 (4.0)	6 (11.8)
Supervised driving hours (total)		
None required	3,472 (77.4)	51 (100)
≤ 20 hours	137 (3.0)	6 (11.8)
25–35 hours	192 (4.3)	6 (11.8)
40 hours	186 (4.1)	11 (21.6)
50–60 hours	501 (11.2)	21 (41.2)
Intermediate stage license age		
No intermediate license stage	2,658 (59.2)	42 (82.3)
< 16 years	389 (8.7)	8 (15.7)
16 years–16, 5 months	1,204 (26.8)	36 (70.6)
16, 6 months–17 years	237 (5.3)	8 (15.7)
Nighttime driving restriction (start)		
No nighttime driving restriction	2,952 (65.8)	45 (88.2)
1 AM	229 (5.1)	8 (15.7)
12 AM	856 (19.1)	24 (47.1)
11 PM	212 (4.7)	10 (19.6)
≤ 10 PM	239 (5.3)	6 (11.8)
Passenger restriction		
No passenger restriction	3,681 (82.0)	51 (100)
2–3 passengers, ≥ 6 months	148 (3.3)	7 (13.7)
1 passenger, ≥ 6 months	279 (6.2)	19 (37.2)
0 passengers, < 6 months	91 (2.0)	5 (9.8)
0 passengers, ≥ 6 months	289 (6.4)	13 (25.5)
Unrestricted license age		
15 years–15, 11 months	252 (5.6)	5 (9.8)
16 years–16, 5 months	2,599 (57.9)	43 (84.3)
16, 6 months–16, 11 months	304 (6.8)	13 (25.5)
17 years–17, 5 months	842 (18.8)	22 (43.1)
17, 6 months–18 years	491 (10.9)	15 (29.4)

Note. GDL indicates graduated driver licensing. No states required supervised driving hours that fell between the categories shown.
‡There are 4,488 quarters per teen age group for grand total of 8,976 quarters.
§The counts add to greater than 51 because some states changed component calibrations over time.

Table 2. Driver Fatal Crash Involvements and Crash Rates per 100,000 Person-years for GDL and Age-Based Teen Licensing System Component Calibrations by Individual Year of Age and for 16-17-year-olds Combined, United States 1986–2007

Component Calibration	16-year-olds				17-year-olds				16-17-year-olds			
	Fatal crashes	Person-years	Crash rate	RR	Fatal crashes	Person-years	Crash rate	RR	Fatal crashes	Person-years	Crash rate	RR
Overall	23,677	84.0	28.2		31,261	84.8	36.9		54,938	168.8	32.5	
Learner stage entry age												
< 15 years	2,013	5.6	35.8	1.0 (ref)	2,345	5.6	41.5	1.0 (ref)	4,358	11.3	38.6	1.0 (ref)
15 years–15, 5 months	14,679	46.2	31.8	0.89	18,235	46.7	39.0	0.94	32,914	92.9	35.4	0.92
15, 6 months–15, 11 months	3,624	13.6	26.7	0.75	4,775	13.6	35.2	0.85	8,399	27.1	31.0	0.80
16 years	3,361	18.7	18.0	0.50	5,906	18.9	31.3	0.75	9,267	37.5	24.7	0.64
Learner permit holding period												
None	12,327	37.9	32.5	1.0 (ref)	15,753	38.5	40.9	1.0 (ref)	28,080	76.4	36.7	1.0 (ref)
< 3 months	3,632	11.8	30.9	0.95	4,382	12.0	36.6	0.89	8,014	23.8	33.7	0.92
3–4 months	1,322	5.1	25.9	0.80	1,674	5.1	32.7	0.80	2,996	10.2	29.3	0.80
5–6 months	5,026	24.3	20.7	0.64	7,520	24.2	31.1	0.76	12,546	48.4	25.9	0.71
9–12 months	1,370	5.0	27.3	0.84	1,932	5.0	38.8	0.95	3,302	10.0	33.0	0.90
Supervised driving hours												
None required	18,735	59.7	31.4	1.0 (ref)	24,128	60.6	39.8	1.0 (ref)	42,863	120.4	35.6	1.0 (ref)
≤ 20 hours	559	3.3	17.1	0.55	904	3.2	28.0	0.70	1,463	6.49	22.5	0.63
25–35 hours	957	3.6	26.7	0.85	1,118	3.6	31.2	0.78	2,075	7.16	29.0	0.81
40 hours	690	2.9	24.2	0.77	974	2.8	34.3	0.86	1,664	5.69	29.2	0.82
50–60 hours	2,736	14.6	18.8	0.60	4,137	14.6	28.4	0.71	6,873	29.1	23.6	0.66
Intermediate stage license age												
No intermediate license stage	14,251	40.8	35.0	1.0 (ref)	17,640	41.4	42.6	1.0 (ref)	31,891	82.2	38.8	1.0 (ref)
< 16 years	1,228	3.4	36.0	1.03	1,660	3.5	47.8	1.12	2,888	6.9	42.0	1.08
16 years–16, 5 months	7,701	34.5	22.3	0.64	10,657	34.6	30.8	0.72	18,358	69.2	26.5	0.68
16, 6 months–17 years	497	5.3	9.3	0.27	1,304	5.3	24.6	0.58	1,801	10.6	16.9	0.44
Nighttime driving restriction												
No nighttime restriction	14,898	42.5	35.1	1.0 (ref)	18,434	43.1	42.7	1.0 (ref)	33,332	85.6	38.9	1.0 (ref)
1 AM	1,181	4.2	28.1	0.80	1,430	4.2	34.2	0.80	2,611	8.4	31.2	0.80
12 AM	4,985	23.2	21.5	0.61	6,864	23.3	29.4	0.69	11,849	46.5	25.5	0.65
11 PM	1,374	6.5	21.1	0.60	2,304	6.5	35.6	0.83	3,678	13.0	28.3	0.73
≤ 10 PM	1,239	7.6	16.2	0.46	2,229	7.7	28.9	0.68	3,468	15.3	22.6	0.58
Passenger restriction												
No passenger restriction	20,133	64.9	31.0	1.0 (ref)	25,888	65.8	39.4	1.0 (ref)	46,021	130.7	35.2	1.0 (ref)
2–3 passengers, ≥ 6 months	614	2.9	21.3	0.69	993	2.9	34.5	0.88	1,607	5.8	27.9	0.79
1 passenger, ≥ 6 months	1,454	6.7	21.5	0.69	2,092	6.7	31.2	0.79	3,546	13.5	26.4	0.75
0 passengers, < 6 months	367	1.3	27.3	0.88	481	1.3	36.1	0.92	848	2.7	31.7	0.90
0 passengers, ≥ 6 months	1,109	8.1	13.7	0.44	1,807	8.1	22.2	0.56	2,916	16.3	17.9	0.51

Table 2 (continued).

Component Calibration	16-year-olds				17-year-olds				16-17-year-olds			
	Fatal crashes	Person-years	Crash rate	RR	Fatal crashes	Person-years	Crash rate	RR	Fatal crashes	Person-years	Crash rate	RR
Component Calibration	16-year-olds				17-year-olds				16-17-year-olds			
	Fatal crashes	Person-years	Crash rate	RR	Fatal crashes	Person-years	Crash rate	RR	Fatal crashes	Person-years	Crash rate	RR
Unrestricted license age												
15 years–15, 11 months	476	1.4	35.1	1.0 (ref)	612	1.4	44.3	1.0 (ref)	1,088	2.7	39.8	1.0 (ref)
16 years–16, 5 months	14,295	39.1	36.6	1.04	17,054	39.7	43.0	0.97	31,349	78.7	39.8	1.00
16, 6 months–16, 11 months	1,448	5.4	26.7	0.76	2,142	5.4	39.6	0.89	3,590	10.8	33.1	0.83
17 years–17, 5 months	5,020	26.8	18.7	0.53	7,604	27.1	28.1	0.63	12,624	53.9	23.4	0.59
17, 6 months–18 years	2,438	11.4	21.5	0.61	3,849	11.3	34.1	0.77	6,287	22.6	27.8	0.70

Note. GDL indicates graduated driver licensing. RR indicates unadjusted rate ratio. Person-years are shown in millions; crash rates are shown per 100,000 person-years.

Table 3. Adjusted Rate Ratios for GDL and Age-Based Teen Licensing System Component Calibrations by Individual Year of Age and for 16-17-year-olds Combined, United States 1986–2007

Component Calibration	16-year-olds ARR (95% CI)	16-year-olds *p*	17-year-olds ARR (95% CI)	17-year-olds *p*	16-17-year-olds ARR (95% CI)	16-17-year-olds *p*
Learner stage entry age						
< 15 years	1.0 (ref)		1.0 (ref)		1.0 (ref)	
15 years–15, 5 months	1.12 (0.91-1.38)	.28	1.06 (0.91-1.22)	.46	1.08 (0.93-1.26)	.30
15, 6 months–15, 11 months	0.98 (0.79-1.23)	.87	1.03 (0.84-1.27)	.75	1.01 (0.85-1.21)	.87
16 years	0.88 (0.68-1.13)	.31	0.93 (0.72-1.21)	.58	0.91 (0.74-1.12)	.37
Learner permit holding period						
None	1.0 (ref)		1.0 (ref)		1.0 (ref)	
< 3 months	1.05 (0.91-1.20)	.53	0.95 (0.85-1.05)	.31	1.00 (0.91-1.09)	.94
3–4 months	1.00 (0.89-1.13)	.98	0.99 (0.91-1.08)	.80	1.00 (0.92-1.08)	.93
5–6 months	0.89 (0.78-1.01)	.06	0.91 (0.83-1.01)	.08	0.91 (0.84-0.99)	.03
9–12 months	0.74 (0.62-0.89)	<.01	0.83 (0.70-0.97)	.02	0.79 (0.69-0.91)	<.01
Supervised driving hours						
None required	1.0 (ref)		1.0 (ref)		1.0 (ref)	
≤ 20 hours	1.03 (0.87-1.21)	.75	1.04 (0.94-1.15)	.42	1.04 (0.93-1.17)	.50
25–35 hours	0.95 (0.85-1.06)	.36	1.06 (0.90-1.26)	.47	1.01 (0.90-1.14)	.88
40 hours	1.14 (1.01-1.29)	.04	1.13 (1.02-1.25)	.01	1.14 (1.03-1.25)	.01
50–60 hours	1.02 (0.92-1.13)	.69	1.05 (0.94-1.17)	.38	1.03 (0.94-1.14)	.51
Intermediate stage license age						
No intermediate license stage	1.0 (ref)		1.0 (ref)		1.0 (ref)	
< 16 years	1.29 (1.08-1.55)	<.01	0.92 (0.70-1.21)	.56	1.05 (0.86-1.30)	.62
16 years–16, 5 months	1.18 (0.99-1.41)	.06	0.99 (0.72-1.37)	.97	1.06 (0.82-1.37)	.66
16, 6 months–17 years	0.77 (0.62-0.96)	.01	1.03 (0.75-1.42)	.83	0.95 (0.69-1.31)	.76
Nighttime driving restriction						
No nighttime driving restriction	1.0 (ref)		1.0 (ref)		1.0 (ref)	
1 AM	0.91 (0.75-1.11)	.35	0.94 (0.66-1.33)	.72	0.93 (0.71-1.24)	.63
12 AM	1.04 (0.84-1.28)	.72	1.02 (0.72-1.44)	.92	1.04 (0.78-1.39)	.77
11 PM	0.96 (0.76-1.21)	.72	0.99 (0.69-1.42)	.94	0.99 (0.74-1.31)	.92
≤ 10 PM	0.81 (0.69-0.95)	<.01	0.97 (0.75-1.26)	.81	0.90 (0.75-1.07)	.24
Passenger restriction						
No passenger restriction	1.0 (ref)		1.0 (ref)		1.0 (ref)	
2–3 passengers, ≥ 6 months	0.98 (0.87-1.11)	.79	1.03 (0.93-1.14)	.51	1.02 (0.91-1.15)	.72
1 passenger, ≥ 6 months	0.80 (0.72-0.89)	<.01	0.88 (0.78-1.00)	.04	0.85 (0.77-0.93)	<.01
0 passengers, < 6 months	1.02 (0.91-1.15)	.72	1.10 (0.89-1.36)	.37	1.08 (0.90-1.29)	.40
0 passengers, ≥ 6 months	0.91 (0.76-1.09)	.29	0.98 (0.85-1.13)	.79	0.95 (0.86-1.06)	.38

Table 3 (continued).

Component	16-year-olds		17-year-olds		16-17-year-olds	
Calibration	ARR (95% CI)	*p*	ARR (95% CI)	*p*	ARR (95% CI)	*p*
Unrestricted license age						
15 years–15, 11 months	1.0 (ref)		1.0 (ref)		1.0 (ref)	
16 years–16, 5 months	0.89 (0.78-1.02)	.10	1.25 (1.07-1.46)	<.01	1.09 (0.93-1.28)	.27
16, 6 months–16, 11 months	0.78 (0.66-0.93)	<.01	1.53 (1.24-1.89)	<.01	1.15 (0.91-1.44)	.24
17 years–17, 5 months	0.74 (0.56-0.97)	.02	1.25 (0.95-1.63)	.10	0.99 (0.75-1.31)	.95
17, 6 months–18 years	0.78 (0.61-1.00)	.04	1.33 (1.02-1.75)	.03	1.05 (0.81-1.37)	.69

Note. Rate ratios are adjusted for the other licensing components shown, state, annual state highway fuel use per capita, changes in state traffic-safety related laws (e.g., seat belt laws), quarterly state unemployment rate, state linear trend and seasonality, and state contemporaneous age 20–24, 25–39, 40–59, and 60-or-older driver fatal crash involvement rates. GDL indicates graduated driver licensing. ARR indicates adjusted rate ratio. CI indicates confidence interval.

Table 4. Teen Licensing System Component Calibrations Associated with the Largest Reductions in 16-17-year-old Driver Fatal Crash Incidence

Licensing system component	Calibration	Clarity of Support
Learner stage minimum entry age	Age 16	Less Clear
Learner permit minimum holding period	9–12 months	Clear
Supervised driving hours	None met criteria	
Intermediate license stage minimum age	Age 16½ to 17	Less Clear
Nighttime driving restriction	Start time of 10 PM or earlier	Less Clear
Passenger restriction	Only 1 teen passenger for 6 months or longer	Clear
Unrestricted license minimum age	None met criteria	

Note. The level of support for these calibrations was deemed to be "clear" if: (1) the calibration rate ratio point estimates suggested 10% or larger decreases in incidence for both 16-year-olds and 17-year-olds, or a 10% or larger decrease for 16-17-year-olds combined; (2) the calibration rate ratio point estimates meeting the first criterion were at least 10 percentage-points lower than for the other calibrations; and (3) for calibrations meeting the first two criteria, none of the rate ratio point estimates were consistent with a 10% or larger increase in incidence for either age group or 16-17-year-olds combined. The level of support for a particular calibration was deemed to be "less clear" if these criteria were met for only one of the age groups. The criteria were applied without regard to the level of statistical reliability of the rate ratios. While the results of this study identify calibrations of individual components that have actually been implemented that are most clearly associated with reductions in fatal crash involvement, they do not incorporate how the components interact, nor do they address the vast majority of teen driver crashes that do not involve a fatality. Therefore, although it seems reasonable to do so, combining these individual calibrations may not create an "optimum" GDL program.

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