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The impact of state laws on motor vehicle fatality rates, 1999–2015

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BACKGROUND: Motor vehicle crash (MVC) fatalities have been declining while states passed various legislation targeting driver behaviors. This study assesses the impact of state laws on MVC fatality rates to determine which laws were effective.

METHODS: Publically available data were collected on driver-related motor vehicle laws, law strengths, enactment years, and numbers of verified-trauma centers. Prospective data on crash characteristics and MVC fatalities 16 years or older from Fatality Analysis Reporting System 1999 to 2015 (n = 850) were obtained. Generalize Linear Autoregressive Modeling was used to assess the relative contribution of state laws to the crude MVC fatality rate while controlling for other factors.

RESULTS: Lowering the minimum blood alcohol content (BAC) was associated with largest declines for all ages, especially the older cohorts: 16 years to 20 years ($B = 0.23$; $p < 0.001$), 21 years to 55 years ($B = 1.7$; $p < 0.001$); 56 years to 65 years ($B = 3.2$; $p < 0.001$); older than 65 years ($B = 4.1$; $p < 0.001$). Other driving under the influence laws were also significant. Per se BAC laws accompanying a reduced BAC further contributed to declines in crude fatality rates: 21 years to 55 years ($B = -0.13$; $p < 0.001$); older than 65 years ($B = -0.17$; $p < 0.05$). Driving under the influence laws enhancing the penalties, making revocation automatic, or targeting social hosts had mixed effects by age. Increased enforcement, mandatory education, vehicle impoundment, interlock devices, and underage alcohol laws showed no association with declining mortality rates. Red light camera and seatbelt laws were associated with declines in mortality rates for all ages except for older than 65 years cohort, but speed camera laws had no effect. Graduated Driver License laws were associated with declines for 16 years to 21 years ($B = -0.06$; $p < 0.001$) only. Laws targeting specific risks (elderly, motorcycles, marijuana) showed no effect on declining MVC mortality rates during the study period.

CONCLUSION: States have passed a wide variety of laws with varying effectiveness. A few key laws, specifically laws lowering allowable BAC, implementing red light cameras, and mandating seatbelt use significantly reduced MVC mortality rates from 1999 to 2015. Simply adding more laws/penalties may not equate directly to lives saved. Continued research on state laws will better inform policy makers to meet evolving public health needs in the management of MVC fatalities. (*J Trauma Acute Care Surg.* 2020;88: 760–769. Copyright © 2020 The Author(s). Published by Wolters Kluwer Health, Inc. on behalf of the American Association for the Surgery of Trauma.)

LEVEL OF EVIDENCE: Epidemiological, Level III.

KEY WORDS: Adult trauma; motor vehicle; fatality; verified trauma center.

Although motor vehicle crashes (MVCs) are the overall leading cause of all unintentional injury deaths for all ages,[1] fatality rates from MVCs have steadily declined in the last two decades for all age cohorts.[2,3] Our previous research focused on how growth in ACS verified trauma centers (vTCs) and driver-related laws influenced trends in MVC fatalities.[4] While growth in vTCs has contributed to declining trends in adolescent and adult MVC fatalities in the 17-year period from 1999 to 2015, the largest contribution to declining trends was made by state laws.[4]

Early research on MVCs identified associated risks for injury and fatality, such as speeding,[5] alcohol impairment,[6] restraint use,[7,8] rural roads,[9] and weather,[10,11] prompted both safety improvements in vehicles and state legislation, sometimes driven by federal laws and incentives.[12] Lower speed limits,[13] red light camera,[14] speed camera laws,[14] primary and secondary seatbelt enforcement laws,[15] child restraint laws,[16] Graduated Driver License (GDL) programs for adolescent drivers,[17,18] and laws specifically directed at prohibiting driving while intoxicated[19] have been adopted by states in an effort to save lives and lower the cost of automotive crashes.[20] Yet, there is a common conflation in the research on crash risks and MVC mortality between crash risks and laws governing crash risks. Considerable research has found crash risks are mitigated by using a seatbelt or not drinking or driving; what we do not know is whether the laws governing use have been effective. The research on the impact of laws on reducing MVC mortality has provided mixed evidence for the effectiveness of laws targeting known risks such as teen driving,[21] seatbelt enforcement for adults and children, red light running/speeding, and driving under the influence (DUI).[22–25] Prevention research has demonstrated the value of assessing time trends in MVC mortality as a forecasting tool for road fatalities and has used associated risks as a way to identify needed policies or laws.[23–25] To date, research has not offered a comprehensive assessment of the constellation of state driver laws targeting known crash risks for all 50 states in the decades since these laws were enacted and their association with MVC mortality trends. The purpose of this research is to address this research gap by evaluating a wide array of state driver-related laws on MVC mortality rates for all 50 states in the period 1999 to 2015 for all ages of drivers. Without such an assessment, knowledge of the effect of driver-related laws on MVC mortality trends is incomplete. Our research also provides a unique window on the interaction between driver behavior, laws, and MVC mortality. Finally, to reduce population mortality, laws should have significant, long-term population impacts. Trauma surgeons, in particular, need a comprehensive

understanding of the associated effects on the population from laws to be effective advocates for laws reducing MVC morbidity and mortality. This study will provide a comprehensive national assessment of motor vehicle laws and time trends in population mortality. This research will inform advocacy efforts by trauma surgeons to promote effective laws and increase population impacts from those laws.

METHODS

Data Collection

Using publically available, prospectively collected data, we conducted a population-based study to assess MVC fatalities for drivers and passengers older than 16 years from 1999 to 2015 for all 50 states. We used a 50-state aggregated time series cross-sectional design appropriate to address the research question. Data on driver and passenger fatalities were obtained from the Fatality Analysis Reporting System (FARS).[26] The FARS data on nonfatalities was not included. We obtained state/year level-specific population data from the Centers for Disease Control and Prevention's Web-based Injury Statistics Query and Reporting System.[27] Fatal MVCs were defined as crashes on public roads with at least one fatally injured person (driver, occupant, or pedestrian older than 16 years) who died within 30 days. The primary outcome was the age-adjusted mortality crude rate defined as mortality per 100,000 for each age cohort (age, 16–20 years; age, 21–55 years; age, 56–65 years; age, >65 years) and calculated by state per year. Age cohorts were constructed to optimize expected effects from driver-related laws.

We constructed new variables measuring seatbelt laws,[15] common drinking laws,[28] speed camera laws, red-light running laws (none or prohibited, 0; yes in limited or all circumstances, 1).[14] Primary seatbelt laws allow citation without another offense; secondary laws permit citation only with another citable traffic infraction. Seatbelt laws were coded as an ordinal variable by state per year on a scale from 0 to 5 as follows: 0, no primary or secondary law; 1, secondary front only; 2, secondary all; 3, primary-front only no secondary law; 4, primary-front only and secondary for rear; 5, primary-all seats.[15] Mature population license laws,[29] alcohol possession in transport laws,[30] and social host liability laws were measured as binary variables for each state per year.[30] For other drinking laws, we constructed ordinal variables. For administrative penalties,[31] we measured the strength of the penalty (first/second/third offense) on a scale from 0 to 6 (0, no laws; 6, up to 1 year for first offense). Mandatory alcohol education/treatment laws were measured on a 10-point ordinal scale from 0 (no laws) to 10 (mandatory treatment on first offense).[31] Vehicle impoundment laws and interlock devices were measured on a scale from 0 to 2 to classify states per year (0, no laws; 1, limited; 2, applicable to first offense).[31] Helmet laws were not included in this study since they target a specific vehicle class, and effects sizes may be influenced by cars and trucks. Helmet laws will be analyzed in a separate study on motorcycle mortality.

Other state laws (per se; alcohol purchase, alcohol-in-transport, vision test required, in-person license renewal) were measured as discrete categorical variables indicating the presence (1) or absence (0) of the law in that state for that year. Blood alcohol content, also called blood alcohol concentration (BAC)

is used to indicate a person's level of intoxication. It is expressed in terms of weight (milligrams) per unit of volume (milliliters). Per se laws pertaining to driving while under the influence of alcohol establish the precedent that if an individual's BAC is more than the legal limit, which in nearly every state is 0.08, they will be categorized as intoxicated and violating the law with no other evidence required. No additional proof of drunken impairment needs to be provided when BAC levels exceed the state limit. This variable was coded based on 0, no; 1, yes. A first time DUI offense without any aggravating circumstances is typically charged as a misdemeanor offense; however, under "aggravating" circumstances, the penalties may be enhanced (Enhanced Penalty Laws). Zero tolerance refers to laws that make it illegal for individuals younger than 21 years to drive with any amount of alcohol in their system. Zero tolerance limits enhanced penalty limits, and BAC limits were measured as a ratio variable (0.02–0.08 by weight per unit volume of alcohol in blood or breath). Two types of drug laws were measured. Marijuana-impaired driving laws were measured on an interval scale from 0 (no law); 1 (THC < 5 ng); 2 (reasonable inference =5 ng); 3 (zero tolerance). Although not a driver law per se, we measured states' decriminalization statutes on a four-point interval scale: 0 (illegal); 1 (medical only); 2 (decriminalized) 3 (recreational legalized). For cell phone driver laws, we measured texting bans on a four-point interval scale: 0 (none); 1 (learner's permit); 2 (younger than 21 years); 3 (all drivers); and handheld bans was also measured on a four-point scale: 0 (none); 1 (learner's permit/younger than 18 years); 2 (school zones only); 3 (school and highway work/road construction); 4 (all drivers).

The GDL law measures were constructed by identifying key components for each law on an ordinal scale. The GDL data were obtained from the Insurance Institute for Highway Safety's website.[32] In addition, we measured GDL strength; an ordinal variable (1–4) was constructed from the Insurance Institute for Highway Safety (IIHS) strength rating system.[33] A complete list of sources and all variables with definitions are provided in Supplemental Digital Content, Appendices A-E (http://links.lww.com/TA/B624).

Additional variables were also constructed as controls. We constructed net trauma center crude rates (per 100,000) for ACS vTCs from the American College of Surgeons website cached by web crawlers over the study period.[34] Crash characteristics were derived from FARS and aggregated to the state level by calculating age-adjusted crude rates. All data were merged via MS-SQL Server Management Studio version 17 (MS 2017) into an MS-Excel version 2010 (MS 2010) spreadsheet containing 50 states and 17 years of data for each state (N = 850). This research was conducted with the approval of Phoenix Children's Hospital Institutional Review Board (PCH IRB: 17–035).

Data Analysis

Generalized linear autoregressive modeling allows researchers to assess the relative contribution of specific changes to the overall mortality while controlling for state variation across the period under study. Trauma system capacity was measured by changes in ACS accreditation year over year for each state. If a state went from no trauma system to a great one in a year or over several years, these effects should be seen in the dependent variable if they were impactful. We also control for state by state variation and as many changes over time as possible by

using a generalized linear autoregressive model (GLAM) which includes fixed (state) and random (time) parameters to capture both types of variation. These "black box parameters" control for any unmeasured variation occurring in that state and any inherent time trends not otherwise captured.

SPSS version 18 (IBM Corp, Armonk, NY), and R-studio version 3.2.0 (R Foundation) were used for all statistical analyses and modeling. Final model was estimated via maximum likelihood techniques for GLAM with a Gamma distribution and log link under an AR (1) covariance structure.[35] p Values of 0.05 (two-sided) were used to determine final model specification. Final model fit was evaluated based on extensions of Akaike's Information Criterion for model selection: the Quasi-likelihood under Independence Model Criterion and the Corrected Quasi-likelihood under Independence Model Criterion.

Pooled time series is a particular type of regression analysis applied to data that combine cross-sections and time series. When the variables for multiple different cross-sections are observed over the same periods, the resulting matrix is a pooled time series. Pooled time series offer the ability to investigate variations that occur over a study period to determine associated risk and protective factors. This makes an ideal tool to research the impact of a wide array of state laws on trends in MVC mortality.

The methodology is designed specifically to manage variability among states across time. Difference in prevalence of state laws is captured in state parameters within the GLAM so that the regression model manages the state by state heterogeneity. Observation of a significant law effect requires both an associated time trend and significant prevalence across states. Lagged effects up to 2 years were also tested for all law variables, but there were no significant lagged effects.

RESULTS

Mean crude fatality rates by age cohort are shown in Figure 1. It shows that the youngest age cohort demonstrated the largest average declines (56%) from 1999 to 2015, while the 56 years to 65 years age cohort demonstrated the smallest average decline (12%); all cohorts experienced upticks in the crude rate from 2014 to 2015.
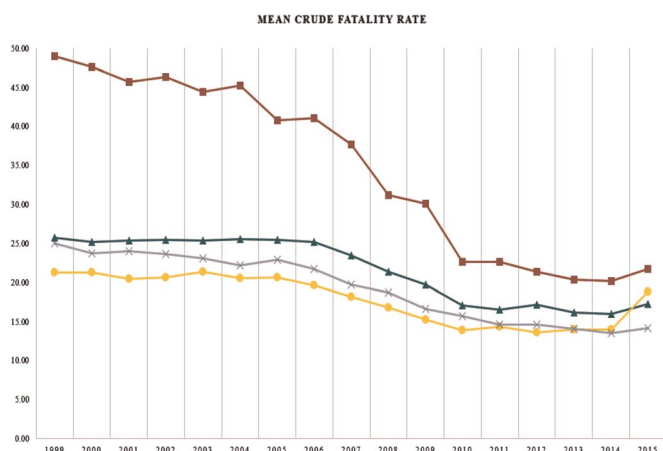

Figure 1. Mean crude fatality rates by age cohort in the U.S. (excluding District of Columbia), 1999–2015.

TABLE 1. Listing of All State Driver-Related Laws

All State Driver Related Laws Measured in This Study
1. Alcohol Laws
1.1 Per se BAC
1.2 Reduced BAC
1.3 Enhanced Penalty BAC Limit
1.4 Zero Tolerance Limit
2. DUI Penalties
2.1 Administrative License Suspension/Revocation
2.2 Mandatory Alcohol Education and Treatment/Assessment
2.3 Vehicle Impoundment
2.4 Vehicle Ignition Interlock
3. GDL Laws
3.1. Permit Period
3.2. Passenger Restrictions
3.3. Unsupervised Driving Prohibition
3.4. GDL Strength
4. Underage Alcohol Laws
5. Social Host Laws
6. Alcohol in Transportation Laws
7. Drugged Driving Laws
8. Helmet Laws
9. Mature Population Driver License Laws
10. General Population Driver License Laws
11. Cellphone Laws
12. Seatbelt Laws
13. Red Light Camera Laws
14. Speed Camera Laws

Table 1 shows all state driver laws enacted during the period. Table 2 shows the final variables used in the regression model to assess the association of driver-related state laws on MVC trends in fatality rates for all age cohorts. Appendix A in the Supplemental Digital Content (http://links.lww.com/TA/B624) describes the crash demographics for all 50 states in the period under study by age cohort.

Some driver laws were associated with steep declines in the rate of age-adjusted population-based fatalities. For the age cohort 21 years to 55 years, state specific DUI laws in particular hastened the declining rate significantly ($B = 1.7$; $p < 0.001$). Lowering the minimum BAC was associated with largest declines in the fatality rates for all adult cohorts, but had the largest effect for older cohorts: 16 years to 20 years ($B = 0.23$; $p < 0.001$), 21 years to 55 years ($B = 1.7$; $p < 0.001$); 56 years to 65 years ($B = 3.2$; $p < 0.001$); older than 65 years ($B = 4.1$; $p < 0.001$). Other DUI laws were also significant. States that implemented a per se BAC law accompanying a reduced BAC also contributed toward declines in crude fatality rates over the period for two age cohorts: 21–55 years ($B = -0.13$; $p < 0.001$); >65 years ($B = -0.17$; $p < 0.05$).

Automatic suspension/revocation laws contributed to declining rates for MVC deaths for those older than 21 years: 21 years to 55 years ($B = -0.07$; $p < 0.005$); 56–65 years ($B = -0.09$; $p < 0.01$); older than 65 years ($B = -0.05$; $p < 0.05$). Social host laws were associated with 21% of the decline in the mortality rate for 16 years to 20 years with weaker effects for age cohort 56 years to 65 years ($B = -0.21$; $p < 0.005$); 10% of decline in the mortality rate for age cohort 21 years to 55 years ($B = -0.10$; $p < 0.001$); and 13% of decline

TABLE 2. GLAM Estimates for State Laws Associated With Time Trends in Crude Fatality Rates by Age Cohort, 1999–2015

Variable	Age Group Cohorts N = 850 Unstandardized Regression Coefficient (p-Value)			
State Laws	16–20 y	21–55 y	56–65 y	Older than 65 y
GDL laws				
GDL strength	−0.06 (0.001)**	−0.05 (0.3)	−0.03 (0.8)	−0.001 (0.5)
Passenger restrictions	−0.10 (0.002)*	−0.02 (0.6)	−0.001 (0.9)	−0.001 (0.9)
Permit period	−0.03 (0.001)**	−0.03 (0.3)	−0.003 (0.9)	−0.002 (0.8)
Learner minimum age	−0.004 (0.3)	−0.02 (0.7)	−0.001 (0.9)	−0.001 (0.9)
Learner minimum education hours	−0.03 (0.8)	−0.001 (0.7)	−0.03 (0.8)	−0.002 (0.9)
Unsupervised driving restriction	0.04 (0.3)	−0.002 (0.6)	−0.001 (0.9)	−0.01 (0.6)
Min age nighttime restriction lifted	−0.003 (0.4)	−0.01 (0.9)	−0.002 (0.8)	−0.001 (0.5)
Min age passenger restriction lifted	0.009 (0.9)	−0.003 (0.8)	−0.002 (0.8)	−0.002 (0.9)
DUI laws				
Alcohol purchase prohibited <21	−0.001 (0.8)	−0.002 (0.7)	−0.001 (0.9)	−0.001 (0.9)
Youth purchase for law enforcement <21	−0.06 (0.8)	−0.001 (0.8)	−0.001 (0.8)	−0.001 (0.9)
Use/lose laws <21	−0.01 (0.6)	−0.001 (0.9)	−0.001 (0.9)	−0.001 (0.9)
Mandatory education	−0.03 (0.8)	−0.01 (0.6)	−0.02 (0.2)	−0.04 (0.2)
Reduced BAC	0.23 (0.001)**	1.7 (0.001)**	3.2 (0.001)**	4.1 (0.001)**
Per se BAC	−0.04 (0.64)	−0.13 (0.001)**	−0.11 (0.34)	−0.17 (0.05)*
Enhanced penalties	−0.02 (0.5)	−0.002 (0.4)	−0.001 (0.9)	−0.08 (0.9)
Suspension/revocation	−0.009 (0.8)	−0.07 (0.005)*	−0.09 (0.01)*	−0.05 (0.05)*
Social host	−0.21 (0.005)*	−0.10 (0.001)**	−0.02 (0.9)	−0.13 (0.07)
Zero tolerance	−0.03 (0.3)	−0.16 (0.2)	−0.21 (0.4)	−0.20 (0.4)
Alcohol possession and consumption in transport	−0.01 (0.4)	−0.05 (0.2)	−0.21 (0.8)	−0.07 (0.3)
Confiscation	−0.02 (0.4)	0.001 (0.9)	0.001 (0.9)	0.02 (0.4)
Ignition interlock	−0.009 (0.7)	0.03 (0.6)	0.20 (0.7)	−0.005 (0.9)
Mature driver laws				
Renewal required >65	−0.001 (0.9)	−0.001 (0.9)	−0.03 (0.6)	−0.06 (0.7)
Proof of vision required >65	−0.001 (0.9)	−0.001 (0.9)	−0.06 (0.6)	−0.12 (0.3)
In-person renewal required >65	0.001 (0.9)	0.001 (0.9)	0.03 (0.7)	0.04 (0.4)
Cellphone laws				
Handheld ban	−0.11 (0.003)*	−0.10 (0.06)	−0.20 (0.2)	−0.08 (0.005)*
Texting ban	−0.02 (0.7)	0.10 (0.4)	0.12 (0.07)	0.09 (0.1)
Young driver texting ban	−0.14 (.4)	−0.30 (0.01)*	−0.02 (0.7)	−0.2 (0.07)
Marijuana laws				
Marijuana decriminalized/legal	0.11 (0.001)**	0.21 (0.003)*	0.07 (0.002)*	0.09 (0.002)*
Marijuana impaired driving	0.0 (0.9)	−0.02 (0.3)	−0.01 (0.2)	−0.01 (0.6)
Other driver laws				
Seatbelt	−0.16 (0.04)*	−0.24 (0.05)*	−0.11 (0.001)**	−0.02 (0.56)
Speed camera	0.02 (0.8)	0.02 (0.4)	0.08 (0.9)	0.05 (0.3)
Red light camera	−0.13 (0.05)*	−0.07 (0.02)*	−0.28 (0.001)**	−0.05 (0.37)

*Statistically significant at $p < 0.05$; **Statistically significant at $p < 0.001$.

in the rate for age cohort older than 65 years ($B = -0.07$; $p < 0.001$). The effects of social host laws were significant only for MVC cohorts 16 years to 20 years and 21 years to 55 years.

There were no effects from speed camera laws for any cohort. Red light camera laws and seatbelt laws demonstrated mixed effects; there were no effects for the oldest cohort from either seatbelt laws or red light laws. For other cohorts, seatbelt effects ranged from 11% for 56 years to 65 years ($B = -0.11$; $p < 0.001$), 16% for 16 years to 20 years ($B = -0.16$; $p < 0.04$) and the largest effects of 24% of the decline in the mortality rate observed for 21 years to 55 years ($B = -0.24$; $p < 0.05$). Red light laws demonstrated the largest effect for 56 years

to 65 years ($B = -0.28$; $p < 0.001$) with smaller effects observed for 16 years to 20 years ($B = -0.13$; $p < 0.05$) and 21 years to 55 years ($B = -0.07$; $p < 0.02$).

Texting bans demonstrated no effects while handheld bans were associated with declining mortality rates for the youngest ($B = -0.11$; $p < 0.004$) and oldest ($B = -0.08$; $p < 0.006$) age cohorts. Young driver texting bans were statistically significant for 21 years to 55 years ($B = -0.30$; $p < 0.02$) but not for young drivers ($B = -0.14$; $p < 0.5$). Specific statutes penalizing marijuana-impaired driving were not associated with changes in mortality rates but general decriminalization was associated with increasing mortality rates for all age cohorts 16 years to 20 years ($B = 0.11$; $p < 0.001$); 21 years to 55 years ($B = 0.21$;

$p < 0.004$); 56 years to 65 years ($B = 0.07$; $p < 0.003$); older than 65 years ($B = 0.09$; $p < 0.003$).

DISCUSSION

Travel by motor vehicle has never been safer than it is today, in part because of federal safety requirements on car manufacturing, such as seatbelts and air bags, state laws regulating risky behavior and trauma systems that deliver high-quality postcrash emergency care in a timely manner. All elements have been critical to saving lives from MVCs.[36] Our research assessed MVC mortality from 1999 to 2015 from the aspect of legislation: Legislation targeting risks and enhancing safety features that have been cited as essential to a comprehensive statewide prevention strategy to reduce road traffic deaths.[36] Although there are decades of research describing the impact of specific driver laws, to our knowledge, this study is the first comprehensive assessment of a wide array of state laws associated with MVC mortality. Our findings indicate that only a few state laws were associated with reducing rates of MVC mortality.

Vehicle safety was one of the earliest targets for driver-related laws. Some of the largest changes in car safety (mandatory seatbelts, meeting federal safety and crash requirements, air bags) occurred prior the study start date but have been revised or enhanced since then.[37,38] Because these vehicle safety requirements occurred prior to the study period start date, as expected, vehicle age was not significant. Surprisingly, one safety feature, a deployed airbag, was an associated risk for mortality trends, suggesting that a deployed airbag was likely acting as a surrogate measure for crash severity in the study period.

Similar to prior research, we found that DUI laws,[39] GDL laws,[39] seatbelt laws,[2,40] and red-light camera laws[41] contributed significantly toward the decline in mortality rates.[22] Laws targeting DUI demonstrated the largest overall effects in the decline of mortality rates in MVC crashes during the study period. The DUI laws have also experienced the largest number of enhancements in states over time, in part based on growth in the adolescent driver population, neighboring states' enacting new laws, and recommendations from research to do so.[21,42,43]

Red light cameras contributed significantly in the decline of overall mortality rates from MVCs, while speed cameras did not. For intersections, following camera installation, it is common to observe an immediate increase in rear-end crashes after camera installation but this effect dissipates over time.[44] The current research suggests that speed cameras are impactful for both intersections and highways in reducing speeders and crashes, but there is no evidence that speed cameras reduce fatalities.[44] By contrast, research on red light cameras suggests that both crashes and mortality have been affected by red light cameras.[12,44]

Research on seatbelt laws has found that primary seatbelt laws tend to be more effective than secondary seatbelt laws, insuring all passengers are restrained in both the front and the back.[40,45] Our results also support this finding. Stronger (primary) seatbelt laws were associated with bigger declines in morality. There was a 23% decrease in the mean passenger death rate for all but the oldest cohort over the study period. Primary seatbelt laws may in part explain this trend. However, our results also suggest that getting drunk drivers off the road did more to push population mortality down than seatbelt laws despite compliance as evidenced by seatbelt use in fatal crashes. Notably, seatbelt laws did not appear to offset mortality risks for older drivers. Age-related risks (reduced response time or medical conditions) may have increased the likelihood of injury severity for older drivers regardless of seatbelt use.

The GDL laws targeting the adolescent age cohort demonstrated a modest effect by contributing 6% to the decline in mortality rates. Prior research has recognized that while the GDL has been an effective tool, it has been difficult to discern which components were effective.[46] Our previous research demonstrated that only a few elements of the GDL were associated with declines in mortality rate for adolescent drivers.[4] Our current results reinforce this finding; only two elements of GDL programs appear to have contributed to declining adolescent fatality trends, namely, passenger restrictions and a longer learner's permit period. Night time restrictions and driver education demonstrated no effect in our current or prior research.[4] States with stricter driver education requirements (greater number of hours) did not appear to mitigate the inherent risk of the inexperienced driver any better than states with fewer hour requirements. This result suggests increasing the minimum driving age and requiring longer permit periods may be more beneficial than increasing education hours. Education hours can be accomplished in a relatively short time frame but experience requires a longer calendar. With regard to nighttime restrictions, fatal crashes may occur on rural roads after midnight on weekends but the majority of fatal adolescent MVCs occur during the day (60%), and more often at busy commuting times (before and after school). The nighttime restriction may not have been as effective because many states incorporated restrictions starting quite late at night, 10:00 PM or later, possibly to accommodate athletic events and teens who work evening shifts. Our results suggest that laws with loose restrictions may have undermined the intended impact of the restriction and, as a result, may have been less effective.

The GDL laws and DUI laws have been the target of numerous legislative enhancements over the years. However, our research suggests that these enhancements were not all associated with declining mortality. Previous research has shown that stricter DUI laws were not associated with reducing fatalities when controlling for population density.[42] Only when high numbers of drivers are likely to be targets of the enhancement would an enhancement be effective in further reducing population mortality. Laws targeting a subpopulation, for example, teens, rather than a geographic location where the risk is increased may undermine the law's effectiveness. Underage DUI may be too rare an event for the law to be associated with mortality trends or alternatively, underage drivers were likely in compliance with general population DUI laws during the period under study, making DUI laws targeted to underage drivers redundant.

Our research shows that some enhancements to DUI laws were associated with declining mortality rates but limited to specific age groups. Social host laws, for example, were meaningful for the 16- to 20-year age cohort and for the 21- to 55-year cohort. It appears holding commercial enterprises accountable for limiting alcohol-related crashes has been a mechanism associated with declining MVC mortality perhaps because these laws target geographic locations where the risk of DUI is increased. State efforts strengthening drunk-driving laws, specifically laws

lowering the minimum BAC, were strongly associated with declines in mortality rates from 20% of the rate of decline for the youngest age cohort to 400% the rate of decline for the oldest age cohort during the period. It is worthwhile to note that recent efforts by some states to strengthen DUI laws further may not produce significant declines in mortality rates. Lowering the BAC from 1.0 to 0.8 was specifically associated with significant declines during our study period. However, our results also suggest that an *additional* reduction from 0.8 to 0.5 may not have a similar significant association because the initial behavior change induced by the law has likely already taken hold in the driving population. In addition, countertrends, such as the availability of ride sharing, may be operating. Further research is necessary to assess how stricter DUI laws and availability of ride sharing may work together in decreasing alcohol-related MVC deaths.

A few other laws, such as automatic revocation and per se laws, demonstrated associations with downward mortality trends but varied by age cohort. Many other laws did not have significant associations, such as mandatory alcohol education, zero tolerance laws, enhanced penalties, interlock devices, and laws targeting elderly drivers. The absence of an association suggests that MVC mortality is unrelated to these laws. These negative findings are worthy of further discussion. While advocacy associations have cited some funded studies to support new legislation regarding interlock devices, there is no independent research suggesting that this technology has reduced MVC mortality. Weak enforcement has often been cited as a reason why certain laws may not have the expected impact.[47] Population clusters (as percent of total population or geographically) tend to facilitate enforcement, thus increasing the certainty of punishment and a law's effectiveness. Laws targeting fairly narrow tranches of drivers may not be associated with population fatality trends because fatalities for the tranche were too rare. Our results suggest that specialized or secondary enforcement approaches (enhancements) may be less impactful when primary enforcement mechanisms (laws and penalties) are strictly enforced. For alcohol impaired driving, the trends suggest that fewer and fewer drivers are alcohol impaired, making the social impact of the law very successful in terms of changing behavior but making the impact of enhancements less and less likely. In short, enhancements may be duplicative of existing laws, for example, per se and zero tolerance. Finally, laws that were more preventative than prohibitive may lack critical deterrence elements to change population behavior, for example, mandatory alcohol education and requiring in-person renewal for drivers older than 65 years.

Laws governing marijuana use and driving, as well as texting and driving, demonstrated mixed results. Unfortunately, both types of laws lack evidence to support the effectiveness of this type of legislation.[36] Driver laws specifically targeting marijuana impairment was not associated with mortality. State laws decriminalizing marijuana, making it legal for medicinal use or completely legal for recreational use for the general population and not just drivers, however, were associated with increasing mortality rates. Our results suggest that impaired driving laws are not offsetting the impacts from decriminalization/legalization. Alternatively, it is possible that impaired driving laws may be targeting a segment of drivers already affected by restrictive state marijuana laws or extant DUI law. As more states legalize marijuana, it may be worthwhile to retest these effects and specifically assess the interaction of legalization and impaired driving statutes within states.

Distracted driving laws have been in place in some states for about a decade, and our results suggest that laws targeting age groups with civil and criminal penalties may not be as effective as laws targeting the device or use of the device in high risk pedestrian areas. Laws that permit targeted enforcement (limiting enforcement to high risk pedestrian zones) and broader bans on handheld devices showed a significant association with declining morality. Targeting young drivers for cellphone use was not associated with mortality for young drivers but was significant for drivers aged 21 years to 55 years. This age group is most likely to travel with passengers and may have been demonstrating good driving practice for teen passengers or may have complied with cellphone restrictions to protect young passengers.

Still, laws alone were not the only factors accountable for declining mortality trends. As previous research suggests, improved trauma systems were also associated with declining mortality trends.[48] The deaths that are nonpreventable after the crash, however, drive the death statistics. This is probably why state laws have such significant impacts. By the 21st century, turning a previously lethal crash into a survivable one is more achievable by altering state laws than in continuing to improve care after the accident.

LIMITATIONS

Many factors change over long periods, and we have used the statistical technique of pooled time series to evaluate the population-based impact of driver-related state laws on MVC mortality. As changes take place in a specific year within a specific state, the other 49 states serve as a comparison group to minimize the impact of environmental factors confounding the true impact on the population-based fatality rate. In an attempt to avoid additional confounding, we also collected and cataloged state trauma capacity for MVC care by trauma center level and verification status and investigated crash characteristics that may moderate the risk of fatality.

Nevertheless, our study has several limitations. Although our study addressed major laws enacted during the study period, states continuously add driver-related laws and enhancements suggesting our results may change as state laws evolve. In addition, some laws targeting specific populations, like motorcyclists or young passengers, may require separate analysis to discern effects. Municipalities may pass stricter laws than the state, thus confounding a state-level analysis. Measures used for changes in laws may not have been sensitive enough to capture small effects or may lack sufficient variation over the cross-section or period to demonstrate effects. We acknowledge that age cohort effects may also require a more nuanced approach than the four age ranges analyzed here; future research may utilize narrower age-ranges and target vehicle types.

Although we included trauma system measures and crash characteristics to control for these confounders, prehospitalization factors, the maturity of the trauma system, prevention strategies, and other state policies influencing driver laws, the quality of enforcement and funding levels for enforcement have not been included. The use of a pooled time series, however, is a strength that mitigates any confounding of our results by unmeasured effects at the state level.

CONCLUSION

The effort to reduce MVC mortalities is a complex interaction of safe vehicles, safe roads, educated drivers, effective legislation targeting driver risks, and an optimized high-quality trauma system quickly providing postcrash services to treat injuries. This study is the first attempt at a comprehensive assessment of the contribution of a wide array of state laws, specific subcomponents of key laws and legislative enhancements to measure an impact on to trends in MVC mortality while controlling for other influences. Our results suggest that MVC fatality rates were successfully mitigated through a few key laws related to drunk driving, red-light running, and utilization of restraint systems. However, our results also suggest that some newer driver risks, such as marijuana legalization, have not been offset with impaired driving laws while other legislation targeting handheld devices does appear to be associated with declining mortality trends. We also found that duplicating extant laws through enhancements or targeting rare, isolated behaviors may not equate directly to lives saved. New laws should be evaluated postimplementation to confirm effectiveness at the population level. Experience from the success of DUI laws, specifically in mitigating MVC mortality rates, further suggests that driver laws need to be targeted for effective deterrence and enforcement. Continued research is needed to better inform driver-related legislation and the long-term management of motor vehicle trauma.

AUTHORSHIP

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DISCLOSURE

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DISCUSSION

HEENA P. SANTRY, M.D. (Columbus, Ohio): I'd like to thank the AAST, members, guests, and Drs. Margulies and Tominaga for the opportunity to discuss this provocative paper by Dr. Notrica and his colleagues.

The authors provided a timely manuscript on their research effort, which I believe is of great public health interest. Dr. Notrica, you have conducted what appears to be an exhaustive examination of various laws intended to improve driving safety beyond the measures to improve intravehicular safety, specifically.

The public health impact of your work will be best achieved with more emphasis, both through text and visuals, on what impact, if any, these multiple laws have, in particular since many of the laws you evaluated are not simply presence or absence of laws, but are more nuanced in practice. If I were a policymaker, I would greatly benefit from more clarity on what laws I could implement or enhance and which laws I should abandon. With this in mind, I do have a few questions.

How would you explain the variable effectiveness of red light camera laws and seatbelt laws based on age group? Assuming that donning a seatbelt is as effective at saving the life of a young person as an older person, is it really just an issue of compliance across different age groups, and if that's the case, how might laws be changed in order to maximize compliance across age groups?

Second, ineffective laws are costly in terms of equipment, law enforcement time, and other unintended consequences. For example, the speed cameras which you found to be ineffective might distract a driver or cause them to behave in an erratic way and lead to an accident. I'm wondering if you found any policies during your analyses that had a paradoxical increase in motor vehicle fatalities.

You commented on the possibility of secular trends that might be unmeasured variables in your outcome of interest, namely, motor vehicle fatalities. Did you make any efforts to adjust for things like the increased availability of rideshare services, or decreasing desire among 16- to 21-year-olds to become licensed drivers, and did this show any impact on overall motor vehicle fatalities?

Finally, based on your extensive analysis across 50 states, can you tell us which state is the safest and which is the least safe, vis-à-vis the chances of dying in an automobile crash?

It seems as if your research could be something akin to the U.S. News & World Report's college rankings or best communities to live in, and I, for one, would be interested in knowing the answer to that.

MARIE L. CRANDALL, M.D., M.P.H. (Jacksonville, Florida): I also congratulate the authors on really highlighting this public health, truly public health victory and some of our laws that work, but I do have two questions. One is similar to Dr. Santry's.

Did you create a heat map that looked at those states that had the greatest change or improvement in motor vehicle fatalities? If not, that would be a pretty neat graphic.

The second is, how did you account for changes in speed limits? So, you know, the Europeans would go on about the speed creep in the United States because when we dropped our, for, you know, fuel economy reasons, dropped our speed limits to 55, there was a dramatic and abrupt decrease in motor vehicle fatalities, but we have crept up.

And in that period of the 90's, there wasn't as much of a change after '99 as there was, let's say, '90 to '99, but there were some increases in speed limits in states. Did you account for that in your analysis?

WALTER L. BIFFL, M.D. (San Diego, California): This is a really interesting and complicated paper. Looking at your graphs, from about 2004 to 2010, there was a steady decrease, and then it leveled out. I want to ask about that level part- and in particular, about marijuana legalization.

We studied FARS data in Hawaii, and from the period before to the period after legalization of marijuana, the number of THC-positive fatalities tripled. So while we are doing a lot of things that are improving survival, there might be some public policy decisions that can have the opposite effect.

In the state of Colorado there was a ten-year progressive decrease in fatality rates, and then after legalization, an upward blip. Are you able to look at interactions of things that are impacting survival in different directions?

DANIEL L. DENT, M.D. (San Antonio, Texas): I am particularly interested in the blood alcohol level laws. It seems to me that lowering the blood alcohol limit from 0.1 to 0.08 would minimally impact enforcement because there has never seemed to be a lot of people at 0.09 who are the problem. However, making this change in the law may have been associated with a higher level of enforcement and interest in enforcing these laws. I'm curious if you have any other data to see if it actually is lowering the legal blood alcohol limit, or if it comes with a bigger package in enforcement.

DAVID M. NOTRICA, M.D. (Phoenix, Arizona): Thank you. Those were great questions. I have to hand it to Dr. Santry. She gave me some of the best questions that I've had on a topic that's complicated. And I really appreciated those questions, because they're actually going to help make the paper better.

Regarding the variable effectiveness on different age groups, while seatbelt laws are equally effective for all age groups, the laws are not. And the laws have a different effect on different age cohorts.

Keep in mind that laws are a psychological construct, and laws are based on a deterrent theory which has two components. There is the certainty, so, how likely is it that they'll get caught, and there's the penalty – how severe is the penalty? Is it enough to change my behavior?

People of different ages have different risk tolerance for different penalties, and that's why we think that we're seeing a difference between different age groups regarding the laws.

There was a question about cost of implementation. This is a tough question. The main reason for installing cameras is to generate revenue for municipalities. We saw a huge increase during the recession as taxation income decreased, and so, the cost of implementation really is hard to calculate, and basically is a net gain. You need to think of red light cameras and speeding cameras as a form of taxation foremost. There are political costs, but those are difficult to measure.

She asked about paradoxical results, and that was a great question. So, we didn't find very many paradoxical results, but one of them that I thought was really neat is that older cars for young drivers are safer. Okay? So, why would that be?

Well, I think part of it is that any car during this timeframe has seatbelts, but probably giving your child a brand new car

may be a risk factor for them getting into a car accident, and so maybe it's a moral hazard.

Regarding ridesharing, I'm personally convinced that ridesharing saves lives, but the reason that ridesharing probably is having this major effect is that ridesharing is the solution. The problem is, "if I go out and have a drink and I get into a car and my blood alcohol level is 0.8, then I'm going to get in trouble" and now we have a solution, which is ridesharing.

So, the question is, what's driving all these people to use ridesharing, and probably it is the lowering of the blood alcohol content that's doing it. At least, that's what our premise is, and that's what we're seeing, so ridesharing is the solution.

The question is, what happens when we drop the limit to zero? So, Utah just dropped their blood alcohol limit to 0.05, and that was in January, so this is a real possibility.

It may get to a point where the law is that if you're going to go out and have one drink of wine for dinner, that you're going to need a driver. And more than likely, that driver is going to be Uber or Lyft or a ridesharing app-based service, to get you home.

Regarding secular trends, there's no question that global trends, changes in young drivers seeking licensings, and economics drive the mortality rate, but we're not really trying to evaluate the trends. What we're trying to evaluate is which laws have a moderating effect on those trends. You need to think about the state laws as being in response to those trends, and that's really the focus of our paper.

Keep in mind, this is a pooled time series, and so, when we talk about secular trends, because it's a pooled time series, the secular trends are "baked into" the analysis and are actually inseparable from it.

Ranking states? That's simply brilliant. I love that idea, and Dr. Sayrs, who is our PhD on the paper, says that we can do that, and we also said we wish we had thought of that.

So, other questions: she also suggested that we make some changes in focus on visuals, and we will do that. The heat map, which was a question from the floor, is a great idea, so basically, we tried to do it with some of the other stuff; it didn't work out so well. We probably could try a heat map for this and make it work

We have no information on changes in speed laws or speed limits.

Walt Biffl's question about the leveling out – I think that since blood alcohol level drops, the dropping from 1.0 to 0.8 was such a huge driver, I think that's why you see it starting to level out is because effectively you've already gotten all the bang for the buck from that.

And then, the marijuana legislation and legalization – because time trends take a long time and require a lot of states, it's going to be a little while before we can get that data; and I assume it will have an impact, but I can't give it to you based off of this dataset that ends in 2015.

And then the last question was from San Antonio about the blood alcohol laws, and the real difference between dropping it from 1.0 to 0.8 is changing the psychology and making it more likely that you're not going to drive that car.

It's not that the 0.9s were the problem – you're absolutely right. It's really a psychological construct. If you can get those drivers off the road or get them to get a designated driver or the equivalent, that's what's saving lives.