

# Complexities of Young Driver Injury and Fatal Motor Vehicle Crashes

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We offer a perspective on the literature discussing the importance of driving for youth, the complexities of learning to drive, and the risks of driving which lead to motor vehicle crashes (MVCs†). Specifically, we discuss important underlying reasons why some adolescents and young adults may be more susceptible to engaging in driving behaviors which result in fatal MVCs; the leading cause of death among 15 to 20 y/o. Some of the factors known to lead to crash fatalities span the domains of cognitive development, distraction, alcohol/drug use, psychosocial development and peer influence, and young driver inexperience. While advancements in driver training, traffic safety legislation, vehicle safety engineering, and emergency/trauma care have helped reduce the prevalence of crashes, we suggest that natural brain maturation which occurs during adolescence and young adulthood may hold unique susceptibilities for young driver crashes. As such, we discuss the importance in using a multidisciplinary research approach, and specifically neuroscience methods, to develop a more compressive understanding of crash risk factors among young drivers. By using a multidisciplinary approach when studying young drivers, we can advance the injury and prevention science as well as inform relevant policies, innovative technologies, comprehensive training and intervention programs which will develop safer young drivers sooner.

## INTRODUCTION

Driving is a wide-ranging behavior throughout American society. Although widespread and beneficial, it is also a highly complex behavior which is typically learned during critical and vulnerable phases of development: adolescence and young adulthood. In this article, we discuss the established literature and offer a perspective on understanding the complexity of young driver

behavior. As youth mature through adolescence and into young adulthood, formative changes occur physically, psychologically, and socially. It is during these periods of maturation when youth are exposed to and learn important behaviors that can help them reach important milestones (e.g., driving) which allow them to thrive and succeed in later life. However, while driving is generally understood to be related to mobility and well-being, in youth, it is

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†Abbreviations: MVC, motor vehicle crash; BAC, blood alcohol concentration; GDL, graduated driver licensing; MLDA, minimum legal drinking age.

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also a well-known social setting where engaging in risky behaviors can lead to serious injury and death. As such, we discuss the factors that lead to fatal MVCs and how they are unique to young drivers. Further, we discuss the importance of bridging and weaving multidisciplinary scientific methods in order to inform science, practice, and policy aimed at reducing motor vehicle crash (MVC) fatalities among young drivers.

### *Epidemiology of Young Driver Motor Vehicle Crashes*

MVCs are a leading cause of injury and death across the lifespan [1]. Even though MVC-related injuries among young drivers outnumbered fatalities more than 100 to 1 in 2017 [2], injury-only crashes are less commonly a point of interest in the public media. This results in a less than urgent public concern for MVC-related injuries when compared to crash fatalities. Frequently, non-fatal injuries are accompanied by high financial burden (*e.g.*, emergency care, hospitalization, rehabilitation costs, etc.) as well as substantial tangible and intangible physical and emotional disabilities, including PTSD, which may persist and markedly diminishing quality of life [3,4]. Therefore, while these crash-related sequelae are non-fatal, they can be equally devastating and life changing for the involved individual and their families and friends.

MVCs continue to be a primary cause of death among young drivers in three distinctly different developmental phases [5]; teens (15 to 18 y/o), and young adults (18 to 20 y/o), and as well as those 21 to 24 y/o. Although MVCs are often most detrimental for young drivers, this population makes up less than 12 percent of the licensed driving population in the US [6]. Nevertheless, it is the first year of independent driving that continues to warrant special attention as it is arguably the most dangerous year of driving; 16 to 17 y/o drivers are twice as likely to be in a fatal MVC compared to 18 to 19 y/o drivers and up to 4.5 times as likely compared to older age groups [7]. In addition, naturalistic driving studies indicate that 16 to 19 y/o drivers have 30.0 crashes per million miles driven compared to 5.3 crashes per million miles driven for experienced adult drivers (aged 35 to 54 years) [8]. New research from naturalistic driving studies also shows that teen drivers (16 to 19 y/o) have twice the near crash rate (81.6 crashes per million miles driven) than experienced adult drivers aged 35 to 54 years (37.3 crashes per million miles driven) [9]. As a result, MVC-related injuries and fatalities among young drivers continue to be a significant and urgent concern not only for driving youth and their families but also for the public's health and safety. We believe that in order to adequately address and prevent crash-injury morbidity and mortality in this vulnerable population, research must use a multidisciplinary

approach to effectively address a host of underlying domains and complex factors which contribute and lead to MVCs.

### *Complications Unique to Learning to Drive During Development*

Driving is an inherently complex task which integrates high level cognitive faculties and motor skills. These faculties include, but are not limited to, working memory, inhibitory control, and attention [10]. In the context of driving, these cognitive faculties translate to driving behaviors such as remembering directions to driving destination (working memory), resist braking for a red-to-green stoplight (inhibitory control), and filtering out extraneous stimuli such as phone notifications (attention). Throughout adolescence and young adulthood, brain areas related to higher level functions (*e.g.*, prefrontal cortex) continue to mature and therefore, so do the cognitive faculties which rely on these structures (*e.g.*, working memory, inhibitory control, attention) [11-13]. Moreover, research indicates that the brain is not fully developed until about age 25, particularly in males [14-16]. Coincidentally, for many teens, it is during this critical period of structural brain and cognitive development when they first begin practicing to drive. Simply put, teens are faced with learning a highly complex behavior (*i.e.*, driving) which relies heavily on their immature cognitive faculties, and if not carried out safely, is a behavior that has real life or death consequences for them as well as others (*i.e.*, their passengers, other drivers/passengers/motorcyclist/pedalcyclists/pedestrians). Given this developmental conundrum, some clarity emerges as to why young drivers have high rates of fatal MVCs.

The ongoing brain maturation is not only related to the maturation of underlying cognitive processes, it is also related to the development of individual personalities and behaviors. While the association between immature cognitive faculties and MVCs can be drawn, youth personalities and psychopathologies are linked to riskier driving behaviors and MVCs [17]. For example, aggressive driving styles have been associated with two common personality characteristics of young drivers (anger and aggressiveness) [18]. Additionally, others have suggested the need to evaluate a wide range of personality measures, such as altruism, normlessness, hostility, anger, empathy, neuroticism, quality of parent offspring-attachment, to better understand aggressive driving styles as these may influence how young drivers engage with their driving environments (*e.g.*, vehicle, passengers, other drivers, road conditions) [19]. When gender is considered, important differences in driving style are highlighted; generally, men drive at higher speeds, are riskier (*i.e.*, riskier driving and enjoyment of risky driving) and

exhibit more hostility towards other drivers. In contrast, women report more patient driving, and higher scores on driver distress/lack of confidence and distractibility/cognitive dissociations [20]. An interesting link between alexithymia and MVCs has been suggested to be a unique form of acting-out among youth with difficulties identifying/describing emotions [21]. Together, these findings suggest a need to evaluate the young driver as a whole (*e.g.*, neurocognitive faculties, personality/psychopathologies, gender, and driving behaviors) in order to clearly understand the unique vulnerabilities of this young population.

Across all driving age groups, distracted and impaired driving are leading contributors to injury and fatal MVCs. While research and prevention efforts continue to focus on reducing distractions behind the wheel, distracted driving remains ubiquitous and a leading attributable factor in injury and fatal MVCs [22]. While driving, meaningful distractions come from both apparent (*i.e.*, hand-held and hands-free cell phone use) and less apparent sources (*e.g.*, in-vehicle infotainment systems designed to assist the driver, passengers in the vehicle, incidents on the roadway). Unfortunately for some teen drivers, the presence of peer-passengers can be detrimental to safe driving behaviors making them more likely to engage in riskier driving behavior [23-26]. This may be related to the natural and critical psychosocial development which occurs during adolescence and young adulthood. One important transition that occurs is a shift in the perceived level of importance of influence and norms from the teens' parent/family to that of their peers. To add to this complexity, learning to drive frequently coincides with this psychosocial developmental shift. These dynamic psychosocial relationships and interactions that influence safe driving behaviors, further point to the need to understand the intricacies of why the young driver-peer passenger context leads to risky driving, putting them at needless risk for crash-injury.

Temporally coupled with the social shift of greater influence on teens coming from their peers is the increase in exposure to alcohol and drugs (*i.e.*, access and use). During adolescence and young adulthood, youth have their greatest exposure and highest use of alcohol and drugs across the lifespan [27]. Impaired driving (*i.e.*, alcohol, drug), a formidable public health challenge, continues to be a major contributor to injury and fatal MVCs. Incidents of youth drinking and driving have gradually decreased in the last 20 years. However, of the 1,830 young drivers killed in a fatal crash in 2017, 24 percent were found to have a blood alcohol concentration (BAC) of .01 g/dL or higher and 20 percent had a BAC of .08 g/dL or higher [28,29]. The high proportion of young drivers killed with a BAC of .08+ g/dL points to the need to consider the role of binge drinking among youth in MVCs

[30]. While impaired driving has historically referred to alcohol, the landscape of impaired driving is rapidly changing as more US states aim to decriminalize and legalize medical and recreational marijuana. This has major implications for young driver safety as well as healthy development of youth. In particular, as more states legalize recreational marijuana, there is evidence that impaired driving (*i.e.*, drugged driving) crashes will increase [31-34]. Considering the implications in terms of harm to self and others, there is a need to explore changes in drinking behaviors specific to young people, such as the emerging phenomena of extreme binge drinking, and youth marijuana use that have more recently drawn greater media and research attention [35,36].

For clear reasons, impaired driving is a primary focus of prevention efforts. However, there is still cause for concern even after acute intoxication has passed. Even while not intoxicated, alcohol and drug use has been associated with impairments in cognitive performance in adolescents and young adults, including working memory, inhibitory control, and attention [37,38]. The impairments to the cognitive facets which are needed for driving, may lead to more high-risk driving behavior resulting in the high rates of MVCs in this population. Prevention and intervention programs which integrate and discuss alcohol and marijuana use in the context of driving while impaired as well as riding with an impaired driver are needed [39]. Specifically, alcohol/drug prevention programs highlighting how alcohol/drug use can influence driving even while not intoxicated can provide a more comprehensive understanding of how young drivers who use alcohol/drugs can be at a greater risk of crash-injury than their peers who are equally inexperienced.

While distracted and impaired driving account for thousands of MVC-related injuries and fatalities every year, there are other attributable factors that are unique to young drivers. Having passed their first licensure exams, recently licensed drivers have less practice and familiarity on the road (*e.g.*, road conditions, traffic settings, road geometry). This inexperience translates into less discernable understanding of the rules of the road, limited skill in routine and safe vehicle control, and an inability to safely navigate through dangerous driving environments and scenarios [28]. Young inexperienced drivers are also more likely to engage in behaviors which put them at greater risk for more serious crashes (*e.g.*, speeding and driving too fast for conditions – nighttime, inclement weather) [40]. For example, teen drivers are more likely to exceed speed limits and less likely to regularly use seatbelts as compared to older drivers [41,42]. Speeding is directly related to crash likelihood, as well as the severity of the crash and injury outcomes [43]. As examples, a study of young driver fatal crashes in Florida revealed that the young drivers were at fault in 62 percent

of the fatal crashes and were overrepresented in crashes with oncoming traffic where the driver lost control before the impact occurred [44]. In North Carolina, researchers found that MVCs resulting from a young driver failing to yield, overcorrecting while steering, or making an improper turn tended to quickly decline with driver age [45]. However, crashes involving young drivers following too close to another driver declined more slowly with age. While most teen drivers mature through these detrimental driving behaviors, many teen drivers succumb from these behaviors in MVCs.

However, it is not only failures in vehicle control that can result in a fatal MVC. By failing to use seatbelts, young drivers place themselves at greater risk for serious and fatal crash-injuries. If not properly restrained within the vehicle at the time of a crash, they have a greater risk of impacting rigid occupant space supporting structures within the vehicle, striking or being struck by a passenger within their own vehicle at a high force, or being ejected/ thrown from their vehicle. While for many drivers inexperience, speed control, and seatbelt use generally all improve over time, in the beginning, particularly for young drivers, each of these driver safety domains are well understood to be related to serious and deadly crashes. Fortunately, while we recognize that each of these behavioral domains are complex, each is also a viable avenue for pursuit of effective prevention and control of MVC-related morbidity and mortality.

### *Select Factors that Have Helped Reduce Young Driver Crash Fatalities*

Over the last 25 years in the US, changes focused on driver safety, driving environments, and emergency medical services have each helped mitigate crash fatalities among all age groups. More specifically, for young drivers, graduated driver licensing (GDL) programs and minimum legal drinking age (MLDA) legislation have and continue to play unique and critical roles in significantly reducing MVC morbidity and mortality. As early as 1996, every US state and Washington, DC began to implement GDL programs with the safety of the teen novice driver in mind [46]. The state administered programs include several stages and components that allow the novice teen driver to graduate first from a beginner stage, where driving is always supervised, to an intermediate stage, where unsupervised driving is allowed but with certain restrictions (*e.g.*, nighttime driving, driving with passengers), and finally into full-independent driving, licensure without any restrictions. Since new teen drivers are inexperienced and uniquely susceptible to peer-passengers, distractions, drowsy driving, and alcohol/drug use, the entire “graduated learning to drive” period is designed to reduce or eliminate these factors by implementing restrictions which carry meaningful pen-

alties for these risky driving behaviors. In practice, GDL programs have been highly effective at reducing young driver crash fatalities across the U.S. [46,47]. In 1996, when the first GDL laws were being adopted in the US, there were 8,074 drivers aged 15 to 20 involved in fatal crashes. In 2017, there were 4,361 drivers aged 15 to 20 involved in fatal crashes [48]. Therefore, GDL programs are evidence of how driver training programs that include a systematic approach to introducing the driving environment (*e.g.*, passengers, nighttime driving) and not only driving basics (*e.g.*, maintain distance between vehicles) can effectively reduce MVC rates among some of the most vulnerable group of drivers.

While GDL programs were intentionally developed to train safer young drivers, other legislation has indirectly reduced the rates of injury and fatal MVCs. MLDA laws increased the minimum legal drinking age to 21 in 1984. Since this change, the number of alcohol-related fatal crashes has decreased dramatically. During the 1970s, 60 percent of MVC fatalities were alcohol related. By 2010 this had dropped to 37 percent [49]. In 2017, 24 percent of young drivers (15 to 20 y/o) killed in a crash, were killed in an alcohol-related MVC. Additionally, the National Highway Traffic Safety Administration has estimated that 31,959 lives have been saved since 1975 due to minimum drinking age laws. Therefore, the positive effect that implementation of the MLDA has had on alcohol-related MVC fatalities and the broad public’s health is clear.

Since the publication of Ralph Nader’s landmark book, “Unsafe at Any Speed” in 1965, and the establishment of the National Highway Safety Bureau in 1966 (now known as the National Highway Traffic Safety Administration (NHTSA)), followed by the issuing of Motor Vehicle Safety Standards (MVSS), motor vehicle manufacturing companies have vastly refined and continue to improve the safety and crashworthiness of passenger vehicles, SUVs, vans, and light trucks. Therefore, we are currently in the era with the most advanced and safest motor vehicles. Safety engineering efforts have led to the advent and routine integration of passenger restraint systems (*e.g.*, seatbelts, advanced airbags systems), crash-force absorbing structural design of the vehicle and now more commonly, the presence of advance driver assistant systems (*e.g.*, electronic stability control, adaptive cruise control, lane departure and front collision warning systems) in vehicles to protect drivers and their passenger. More recently, crash avoidance systems continue to advance and include technologies such as blind-spot warning, heads-up display night vision, and brake-assist/automated braking, which in the case of the latter, allows the vehicle to “take control” of the car from the driver to reduce the likelihood and/or severity of a crash. While some of these engineering advancements have shown

safety benefits in real-life day-to-day driving, others have yet to be rigorously evaluated within the injury prevention/life-saving context.

Historically, sound policy legislation and advanced engineering have dramatically improved the landscape for all drivers, significantly contributing to the reduction in the number of MVC-related fatalities. This is particularly true for young drivers. Unfortunately, the number and the rate of young driver injury and fatal crashes per mile driven remains high. Research must pursue a more comprehensive understanding of the complexity of factors involved in young driver crashes with particular focus in capturing developmental considerations of a biological, behavioral, and environmental nature in the context of driving to eliminate crash injury.

### *Future Directions: How Neuroscience Can Shape Driver Safety Programs for Safer Young Drivers*

One common discussion aimed towards preventing injury and fatal MVCs focuses on the recent advancements in vehicle automation. Arguably, considerable progress has been made in the automation of vehicles. At face value, it would seem that autonomous vehicles could be the answer for MVC of all types. Related to this, the “Driver Alcohol Detection System for Safety” (DADSS) is a group of technologies currently being tested to prevent impaired driving. These technologies passively detect a driver’s blood alcohol concentration (BAC) via the driver’s breath or tissue (without a specific action by the driver) and if the BAC is over the limit for driving, the vehicle will not drive (<https://www.dadss.org>). However, most experts would agree that we are at the very least a decade or more, with emphasis on the “more” (in specific unique geographic locations), away from fully autonomous cars where the vehicle performs all driving functions with no driver engagement in the process [50]. While considering the many mobility and safety benefits a fleet of fully automated vehicle may have to offer to communities across the country, today, we are still confronted with a consistently high burden of injuries and fatalities due to MVCs. With this in mind, we cannot wait for vehicles with fully integrated automated technologies to eliminate crashes. Therefore, we need to explore and examine innovative and multidisciplinary scientific paths (*e.g.*, brain-based understanding of driver behavior, neurocorrelates of driving) that will lead to the development of effective driver education, training, and crash prevention programs reducing crash injuries and deaths.

Young drivers are at a heightened disadvantage while behind the wheel for several reasons (*e.g.*, susceptibility to distraction, peers, alcohol/drugs, inexperience, high-risk behaviors, underlying brain maturation, personality/psychopathology). Therefore, studying the brain in the context of teen and young adult drivers will provide

novel and valuable insight which will inform intervention and prevention programs. Among young drivers, we can specifically develop our understanding of the neural mechanisms which lead to the unique vulnerability teen and young drivers face and specifically put them at risk for fatal MVCs. By coupling cognitive neuroscience methods with high-fidelity driving simulation, researchers can directly study young driver behavior and related neural mechanisms in a completely safe environment. Therefore, researchers will be able to identify patterns of neurocognitive correlates with driving behaviors (*e.g.*, speeding, vehicle control) and other related behaviors of interest (*e.g.*, distraction, peer influence, alcohol/drug use, cognitive maturation). From naturalistic driving studies, we should be able to determine answers to the following questions: When young drivers make mistakes and a crash or near-crash occurs, was it a lack of perception of the hazard by the driver (*e.g.*, did not anticipate the hazard); or was it a lack of understanding or comprehension that it was a hazard (*e.g.*, did not recognize the hazard; look, but did not see); or was it a faulty decision by the driver in reacting to the hazard (*e.g.*, steering instead of braking); or was it simply a physical error in the action taken by the driver (*e.g.*, oversteering and loss of vehicle control)? [51]. Therefore, by integrating neuroscience, cognitive, personality measures, and high-fidelity driving simulation research methods, we have a valuable opportunity to uncover the brain mechanisms which relate to safe and/or risky driving practices and behaviors.

To this end, researchers could develop studies to understand the neurocognitive functioning (*e.g.*, working memory, response inhibition, attention) and driving behaviors (*e.g.*, speeding, lane maintenance, headway control) which correlate with patterns of alcohol use among teen drivers. In turn, we will be able to translate these multifaceted profiles from a clinical laboratory environment to the applied setting by informing driver education and training programs which integrate these key factors that lead to fatal MVCs. The training programs developed from multidisciplinary studies would use a multifaceted view of the teen driver to train safer young drivers. The programs would educate the young driver on how their decisions out of the vehicle (*e.g.*, alcohol and drug use) translate to a greater risk for a fatal MVC; hopefully further reducing the rates of teen driver fatal MVCs.

## CONCLUSIONS

Factors which lead to high rates of fatal crashes among young drivers are multifaceted and complex. Reducing fatal MVCs is of critical importance considering the high rates of young driver death which persist. Further, crashes among young drivers have great relevance to the public’s health and safety as drivers of all ages share

the roadways. The need to develop safer young drivers sooner is emphasized by the many tangible and intangible benefits that independent transportation adds to an individual's overall well-being and opportunity to flourish in life. Fortunately, meaningful changes in legislation, improvements in vehicle crashworthiness, and advancements in emergency care have drastically reduced fatal MVCs across all age ranges. However, we believe that identifying novel prevention methods, effective policies, and innovative technologies, through multidisciplinary research will significantly reduce young driver crash-injury and fatality statistics. Integrating multidisciplinary research methods which are commonly used to study adolescents, young adults, and/or driving behaviors will provide a more in-depth perspective and potential profile of those who are most likely to engage in high-risk driving behaviors. By defining such phenotypes/profiles, we may be able to identify those who are most likely to engage in high-risk driving behaviors and directly shape programs to better educate and train young drivers.

In sum, young developing populations have unique vulnerabilities which result in MVC injuries and fatalities. MVC injuries and deaths have lasting effects on the young driver involved as well as their family and community which span physical, emotional, and financial burdens. Here, we have discussed the underlying correlates (*e.g.*, brain maturation, psychosocial development, alcohol/marijuana use) of the unique factors (*e.g.*, cognitive functioning, distracted driving, high-risk behaviors, personality/psychopathology) which lead to high rates of MVCs among young drivers. Further, we suggest a multidisciplinary approach (*e.g.*, neuroscience, cognitive and personality measures, and high-fidelity simulation) to be the most beneficial and effective way to develop our understanding of these vulnerable populations. Together, this multifaceted understanding of young drivers and their vulnerabilities will advance the field and inform policies/programs to help save lives by further reducing MVC injury and fatalities; a primary cause of death among adolescents and young adults.

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