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Adolescence, Attention Allocation, and Driving Safety

Daniel Romer, Ph.D.[a,*], **Yi-Ching Lee, Ph.D.**[b], **Catherine C. McDonald, Ph.D., R.N.**[b,c], and **Flaura K. Winston, M.D., Ph.D.**[b,d,e]

[a]Annenberg Public Policy Center, University of Pennsylvania, Philadelphia, Pennsylvania

[b]Center for Injury Research and Prevention, Children's Hospital of Philadelphia, Philadelphia, Pennsylvania

[c]School of Nursing, University of Pennsylvania, Philadelphia, Pennsylvania

[d]The Division of General Pediatrics, Perelman School of Medicine at the University of Pennsylvania, Philadelphia, Pennsylvania

[e]Leonard Davis Institute for Health Economics, University of Pennsylvania, Philadelphia, Pennsylvania

Abstract

Motor vehicle crashes are the leading source of morbidity and mortality in adolescents in the United States and the developed world. Inadequate allocation of attention to the driving task and to driving hazards are important sources of adolescent crashes. We review major explanations for these attention failures with particular focus on the roles that brain immaturity and lack of driving experience play in causing attention problems. The review suggests that the potential for overcoming inexperience and immaturity with training to improve attention to both the driving task and hazards is substantial. Nevertheless, there are large individual differences in both attentional abilities and risky driving tendencies that pose challenges to novice driver policies. Research that can provide evidence-based direction for such policies is urgently needed.

Keywords

Adolescent; Driving; Motor vehicle crash; Inattention; Novice driver policies

Motor vehicle crashes are the leading source of mortality and morbidity in adolescents in the United States and most developed countries [1], and along with older drivers (ages 75 years +), adolescents (under age 20 years) have the highest rates of crashes per mile driven [2].

*Address correspondence to: Daniel Romer, Ph.D., Annenberg Public Policy Center, 202 S. 36th St., Philadelphia, PA 19104-3806. dromer4@gmail.com (D. Romer).

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Driver inattention is a major source of crashes for both adults [3] and adolescents [4,5], with developmental factors playing a role for both older and younger drivers. For older drivers, the risk is a loss of cognitive and motor skills that can impair the ability to recognize and respond to road hazards and conditions [6,7]. For adolescent drivers, the risk is incomplete maturation of cognitive and motor skills, including working memory [8], visual-spatial attention [9], and speed of processing [10]. However, adolescents are also novice drivers, and so it is important to separate the effects of inexperience from developmental factors, in particular whether adolescents lack the *ability* to attend to driving tasks and road hazards due to immaturity in brain development [11,12], or are more susceptible to errors of misallocated attention due to *inexperience*. The former explanation would suggest delaying full licensure for adolescents until they have the requisite maturity to drive safely; while the latter would suggest more modest policies that consider both brain maturation and experience as important influences on adolescent driving ability.

There is reason for optimism regarding the role of experience. Efforts to enact three-stage graduated driver licensing (GDL) provisions have succeeded in reducing by nearly half the recent number of fatalities in crashes with adolescents behind the wheel [13–15]. Recognizing the key roles of maturity and experience on crash reduction, GDL's benefits were determined to result from restricting new young drivers' exposure to more challenging driving conditions. These restrictions are justified based on the continued reductions in crash rates that occur over at least the first 2 years of fully licensed driving, even in adults [16,17]. Nevertheless, a primary effect of GDL is likely attributable to brain immaturity, in that the first two stages of GDL (learner and provisional licenses) restrict the youngest drivers with the greatest crash risk (ages 16 years and younger) from driving under either unsupervised or high-risk conditions (e.g., nighttime driving). More recent provisions address growing recognition of the role of inattention on crash causation by limiting peer passenger carriage and cell phone use. Requirements for adult-supervised practice driving during the learning period also increase the chances that novice adolescent drivers will gain experience before driving independently, and some evidence suggests that this may further reduce the risk for young drivers, especially when the period lasts for 12 months [18].

In this paper, we consider the role that both maturation and experience play in the allocation of attention to driving tasks. Some of the most prevalent crash configurations in adolescents, rear-end collisions, running off the road as a result of failing to negotiate a curve, and left turns at intersections [19], all have the potential to involve errors of attention [20,21]. Therefore, in this paper, we provide a foundation for future interventions and research regarding failures of attention among adolescent drivers. We first provide a model for categorizing various forms of inattention that can affect driver safety in novices. We then consider how both brain maturation and driving experience might affect those forms of inattention. We end with potential approaches to training and the need for future research that can enhance attentional skills in novice adolescent drivers. Although we focus primarily on studies of adolescents, we include research with adults when it is relevant to determining the effects of maturation versus driving experience.

Distinguishing different categories of inattention

The most widely accepted definition of driver inattention from Regan et al. [22], "insufficient, or no attention to activities critical for safe driving" (p. 1,775), broadly implies that the driver fails to allocate sufficient attention to the driving task in comparison with tasks that compete for attention. For the purposes of this review (see Figure 1), we further divide these activities into those that involve (1) failure to allocate attention to the road due to various forms of distraction or inability to maintain attention to the driving task (task inattention); and (2) failure to attend and respond to hazards even if one pays attention to the driving task (hazard inattention). We treat failures of attention to hazards as the proximate cause of crashes, and failures to attend to the driving task as one potential source of hazard inattention.

The model treats distraction as a relatively *transient* source of task inattention, or "a diversion of attention away from activities for safe driving…," as for example, attending to vehicle controls rather than the road [23]. For novice adolescent drivers, it is also important to consider potential *stable* sources of task inattention that stem from immature brain development or from chronic conditions, such as attention deficit/hyperactivity disorder (ADHD), the most common neurodevelopmental disorder in children and adolescents [24].

Figure 1 details various transient conditions that result in task inattention, some of which are longer in duration (e.g., physical inability to attend, such as drowsiness or alcohol intoxication) compared with more momentary distractions (e.g., dialing a cell phone, or attending to interesting people or scenes on the road). Also included in this category is mind wandering, when drivers monitor the road but focus their thoughts elsewhere [25].

Studies that examine brain activity while subjects engage in simulated driving tasks shed light on why even minor lapses in task attention can interfere with driving capability and reduce the ability to recognize hazards. These studies use functional magnetic resonance imaging to observe brain activity and have found that engaging in a cognitive task such as speaking on a phone while driving reduces activation in posterior visual regions and increases activation in frontal regions [26,27]. This can impede attentional resources directed to the visual field even though subjects outwardly maintain attention to the driving task. For example, a study using a driving simulator found that talking on the phone while driving reduced attention and response to a vehicle braking in front of the driver [28]. Mind wandering while driving can also divert attention from the visual field [25], suggesting that one does not need an explicit distractor, such as conversation with passengers or by cell phone, in order to experience attention failures. Nevertheless, the kind of driving activities that might be degraded by concurrent cognitive challenges is not clear. For example, Cao and Liu [29] found that staying within a driving lane was not affected by a concurrent comprehension task. In addition, the role of context plays a role in an adolescent's engagement in distracting activities; for example, a recent naturalistic driving study found the use of electronic devices was reduced in the presence of peer passengers [30].

Figure 1 distinguishes two major sources of hazard inattention apart from failure to attend to the driving task. Even if a driver is attentive to the driving task, he or she may still be at risk for crashing due to a relatively *stable* failure to recognize and respond to potential hazards, an important source of driver error, especially in novice drivers [31–33]. Novice drivers lack the skills to effectively and efficiently recognize and respond to hazards; that is, they are often untrained in proper scanning and may focus on noncrucial elements in the driving scene [34]. In the driving literature, the failure to attend to and recognize hazards results from the lack of cognitive and motor schemas that are gained from experience in driving and that enable the driver to recognize and respond appropriately to hazards, an ability known as *hazard or situation awareness* [34].

Situation awareness grows from the development of schemas that enable the *perception, comprehension, and prediction* of relevant driving cues [35]. Adolescents can have deficits stemming from both immaturity and inexperience in all three of these schema-related functions. Safe driving requires adequate scanning, far ahead and to the sides, which requires the ability to maintain attention to the driving task [36]. Further, the driver needs cognitive capacities, such as working memory ability, to be able to attend to the cues that are most relevant for safety [37]. Upon encountering a hazard, the driver must comprehend it as such and focus attention on the most relevant elements of the scene [34]. Finally, the driver must be able to predict and plan for any potential collisions or other negative consequences and act quickly to avoid or mitigate crash risk. In short, driving requires dynamic control over both attentional and motor resources, a skill that requires development of all three functions of situation awareness.

The effects of inexperience can be exacerbated by other forms of brain development that encourage risk taking during adolescence. One such change is the rise in sensation seeking that peaks during adolescence [38,39]. Sensation seeking is the tendency to seek novel and exciting experiences despite the potential for negative consequences [39]. A related characteristic that is also greater in adolescents is impulsivity, the tendency to act without adequate consideration of the consequences [40]. Both tendencies are stronger in males [41] and have been the focus of commentaries on the role of brain development in adolescent risky driving [11,12] However, unlike sensation seeking, impulsivity is characterized by a deficit in attention skills [41], an extreme form of which is apparent in ADHD, which presents with both impulsive and attentional problems [42]. When the effects of sensation seeking are separated from impulsivity, impulsivity appears to be the more serious predictor of risky behavior [43,44]. Nevertheless, both impulsivity and sensation seeking may place adolescents with weak situational awareness in harm's way while driving [45]. For example, sensation-seeking drivers who are not aware of the importance of certain hazards (e.g., safe speed when turning) may drive too fast while negotiating curves. Impulsive drivers may drive too fast and ignore hazards because they do not attend to and consider the consequences to themselves or others.

Although sensation seeking and impulsivity decline as adolescents enter adulthood, individual differences in these characteristics would be expected to continue to influence driving into adulthood, with impulsivity the more serious of the two. Indeed, considerable research finds individual differences in adolescent risk-taking tendencies that are related to reckless driving [46,47]. Interestingly, sensation seeking does not appear to be strongly related to crash risk when important mediators, such as drug use [48] and driving with multiple passengers [49] are controlled. This pattern is consistent with the hypothesis that sensation seeking is a risk for hazardous driving primarily when it involves behaviors related to impulsivity.

Failure to focus on hazards can also stem from transient influences that can afflict both experienced and inexperienced drivers. Two notable examples of such failures indicated in Figure 1 include phenomena called "change blindness" [50] and "inattention blindness" [51,52]. A famous example of inattention blindness occurs when perceivers focus on events of one kind (people tossing a ball) but ignore the presence of a salient event, such as a gorilla traversing the field of vision (see http://www.youtube.com/watch?v=z-Dg-06nrnc). This is even possible for expert observers [52]. Such phenomena involve obvious changes in a scene that can go unnoticed if attention is directed toward another part of the visual field or interrupted by an eye blink [53]. In the driving literature, these attention errors are known as "looked but failed to see" [54]. An example of change blindness during driving might involve the failure to notice a new traffic sign on a familiar road [55], while inattention blindness, common in adolescent drivers, might involve physically moving the head/eyes left-right-left without perceiving or comprehending a potential hazard in the driver's path.

Cognitive deficit versus incomplete development of situation awareness in novice drivers

Potential explanations of attention errors in novice drivers focus on limitations in cognitive resources that prevent the driver from allocating adequate attention to the driving task versus explanations that focus on incomplete development of situation awareness [34]. Both explanations could be consistent with deficits in brain maturation in adolescent drivers. Thus, we first consider whether maturation of attention abilities in adolescents is sufficient to support safe driving.

Maturation of attention in adolescent drivers

Psychological research led by Michael Posner [56] has identified three types of attention governed by different brain circuits: alerting, orienting, and executive control, each of which is critical for the development of situation awareness. The alerting system controls the ability of the brain to sustain attention to the environment and is obviously critical for managing attention to the driving task. The orienting system controls shifts in attention that respond to events requiring immediate action, such as potential hazards. The executive control system enables one to focus attention on the cues that are most diagnostic for task purposes, and to avoid distractions both external and internal to the vehicle that can interfere with safety.

Posner's research indicates that performance on orienting and executive control tasks are independent of each other once a sufficient level of alerting is present. Furthermore, the developmental trajectory of orienting is largely complete by age 10 years. In his tests, the alerting system continues to develop into adolescence [57]. However, other research suggests that the executive control of attention, indexed by tasks that assess the ability to inhibit a prepotent response, such the Stroop task, takes longest and may not reach asymptote until late adolescence [9,58]. An important study of the development of the executive ability to inhibit a dominant response used the “stop signal paradigm,” in which a frequent “go stimulus” signals the need to respond, while a “stop signal” occasionally occurs just after the go signal requiring the person to stop [59]. Using response time (following the stop signal) as an index of the ability to inhibit a response, this ability increases sharply from childhood through adolescence before leveling off in young adulthood where it remains relatively stable until age 60 years +. Nevertheless, despite this developmental trend, there are considerable individual differences in inhibitory abilities even in adults. It may well be, therefore, that the majority of late adolescents have the attentional skills needed to cope with typical driving tasks, even those that require fast responses to stop a vehicle.

An extremely sophisticated analysis of the ability of drivers to respond to hazards was recently completed by Dozza [60], using a record of naturalistic driving in the Virginia Tech Transportation Institute study of 100 adult drivers. The study was able to record the gaze direction of adult drivers as they encountered potential hazards and the time it took them to apply brakes and steer out of danger. Not surprisingly, they found that drivers who were looking away from the road at the time of the hazard took longer to respond than those who were focused on the road. However, there was no difference in response time between drivers ages 18–20 years and 21–50 years. Older drivers ages 51–65 years took slightly longer to respond. Consistent with the Dozza study, a study of younger (under age 25 years) and older drivers (age 30 years +) in a simulated driving environment found that in-vehicle distractions, such as use of entertainment equipment and conversation with others, interfered with responsiveness to potential hazards to the same degree in both younger and older drivers [61]. Thus, there is reason to believe that younger drivers may be able to respond as quickly following an attention lapse as older drivers.

A recent study examined individual differences in each of Posner’s attentional systems in relation to various kinds of performance on a simulated driving test in young adults [62]. The study found that only individual differences in orienting were related to driving performance. Interestingly, there was one case in which better orienting was a hindrance to performance. In that case, attending to one safety cue prevented the driver from seeing other cues that were more important in the situation. A similar phenomenon has been noted in research on inattention blindness [52]. This type of inattention highlights the reality that global attention skills may not predict safe driving under all conditions because having good ability to orient to one cue may interfere with noticing other changes in the visual field that are critical for situation awareness. Thus, theories of attention as applied to driving focus on the development of skills that enable the driver to anticipate relevant cues in the environment so that distracting cues are ignored and errors of attention are minimized. Such errors of attention should be less likely to afflict experienced drivers who over time learn to recognize critical safety-relevant cues and hazards [63,64].

Stable attention conditions: the case of attention deficit hyperactivity disorder

Despite the importance of experience in learning to drive, one would expect adolescents with attention deficits to encounter greater difficulties in driving [65]. A meta-analysis of studies comparing drivers diagnosed with ADHD to drivers matched without the condition found greater history of crashes and traffic citations fordrivers with the condition [66]. Studies examining the sources of the difference have found evidence of both attentional deficits and greater impulsivity in drivers with ADHD [67,68]. Research using the Posner system to diagnose attentional problems in children with ADHD suggests that they suffer from deficits in both the alerting and executive control systems [69], both of which are consistent with the beneficial effects of stimulant medication for this disorder. Indeed, there is preliminary evidence that stimulant medication can reduce driving impairments associated with ADHD in simulated driving performance [70].

A study conducted by Reimer et al. [71] provided insight into the conditions under which young people (age 20 years) with ADHD exhibit driving risks under divided attention. When driving in a simulated urban environment with a low speed limit, persons with ADHD did not exhibit deficits in driving performance despite making more errors in a secondary task. However, when driving on a simulated open highway with a 65-mile-per-hour limit, they did exceed the speed limit more than comparison drivers. They also did not exhibit deficits in the secondary task. These findings suggest that although young drivers with ADHD may focus their attention to the driving task under more complex driving conditions, they are likely to do so with more limited attentional resources than persons without ADHD. On the other hand, when driving on an open highway with lower attentional demands, persons with ADHD may still be able to monitor secondary tasks, suggesting that their deficit under these conditions is more related to impulsive driving tendencies than to attentional deficits.

Attention allocation effects on hazard detection

The hypothesis that novice drivers fail to recognize hazards because they lack fully developed situation awareness can be contrasted with explanations that focus on the cognitive deficits that novice drivers might experience due to their inability to cope with the complexity of the driving task [34]. In the model in Figure 1, the cognitive deficit explanation focuses on the inability to adequately allocate attention to the driving task, while the situation awareness hypothesis focuses more so on incomplete knowledge of and importance of driving hazards. Considerable evidence from simulated and on-road tests supports the situation awareness hypothesis [34]. For example, even when novice drivers do not have to control a vehicle, they still show deficits in attention to potential hazards in more complex driving environments [32,34]. Indeed, a major difference between novice and experienced drivers is the failure of novices to scan the roadway effectively for potential hazards, especially under more complex road conditions [32,34].

A recent study showed that both novice adolescent drivers and older more experienced drivers are impeded from recognizing hazards when they divert attention to signs on the road [72]. Although both groups spent equal amounts of time looking at the signs, experienced drivers were affected less, suggesting that their greater ability to maintain situational awareness enabled them to recognize hazards despite being diverted by an alternative task.

Also consistent with the situation awareness hypothesis, training to attend to likely hazards in complex environments reduces deficits in attention to potential hazards [73,74]. Surprisingly, merely encouraging novice adolescent drivers to verbalize the presence of potential hazards while driving increases attention to hazards [73,75]. This suggests that increasing awareness of the importance of hazards can be sufficient to increase attention to them. Furthermore, hazard perception training can reduce tendencies to speed, indicating that greater appreciation for the risks of driving may discourage risky driving practices [76]. These findings are consistent with the hypothesis that situation awareness in novice drivers is weak in comparison with experienced drivers and that this deficit is not the result of limitations in cognitive resources devoted to allocating attention to the driving task.

Prevalence and effects of inattention in adolescent driving

We now turn to the many sources of inattention that can affect adolescent drivers. Here we focus on the contrast between the adolescent as a driver lacking in situation awareness versus one engaging in deliberately reckless forms of behavior, a sign of sensation seeking or impulsivity [11,12]. Two studies are informative regarding these two potential sources of driving errors in adolescents. McNight and McNight [5] examined sources of teen driving problems in a survey of 16- to 19-year-olds in two states. They concluded that "the great majority of non-fatal accidents resulted from errors in attention, visual search, speed relative to conditions, hazard recognition, and emergency maneuvers…rather than to high speeds and patently risky behavior…"

A second recent analysis of teen crashes based on the U.S. National Motor Vehicle Crash Causation Survey (NMVCCS) found that nearly half of serious crashes (46%) were attributable to what might be categorized as inattention in Posner's system [4]. This included failures of surveillance as well as distractions and mind wandering. The second largest category (40%) included driver decision errors, such as driving too fast for the conditions, misjudging another car's speed or distance (i.e., those that can result from inexperience), and errors due to aggressive driving. It was noted that aggressive driving accounted for less than 3% of the crashes, suggesting that reckless driving was much less a source of crashes than lack of experience. The authors noted that too often public health efforts "focus on preventing teen 'problem' behaviors instead of focusing on the skills they need to develop as skilled drivers." Both studies found that female drivers were more likely to make surveillance errors; however, the studies differed as to whether males were more likely to drive too fast for the conditions. Indeed, the study of actual crashes found that females were more likely to make that error [4].

Cell phones as sources of inattention

Driving while using cell phones is associated with increased crash risk [77]. Three quarters of U.S. adolescents use mobile communication technologies, including cell phones [78]. Although adolescents are often characterized as the most avid adopters of mobile technology, U.S. adults under the age of 50 years use mobile technologies at about the same rate [79]. Furthermore, a study of the effects of cell phone use in a simulated driving environment [80] found that cell phone use was equally distracting to novice adolescent drivers ages 14–16 years as to more experienced adult drivers ages 21–52. Measures of situational awareness revealed that both groups suffered deficits in awareness of driving conditions that could affect hazard detection. The researchers attributed the effects of cell phone use to increased cognitive load that interfered with the ability to maintain situational awareness. However, the brain imaging research cited earlier [26,27] suggests that even removing the need to hold or dial the phone (e.g., using voice-activated technology), will not eliminate all aspects of distraction created by talking on phones.

Texting while driving may be an even greater risk because this behavior greatly impedes attention to the road. A study in a simulated driving environment showed that engaging in even very brief texting interfered with driving safety in adult drivers [81]. Young adult drivers (ages 18- to 21 years) also exhibited adverse effects of texting while driving in a simulated environment [82]. The drivers spent less time looking at the road and missed signs directing them to change lanes.

Studies of the prevalence of cell phone use while driving suggest that it is a serious risk for both adults and adolescents. A recent national survey of drivers ages 16 years + found that about one third could be classified as distraction prone, meaning that they admitted to engaging in various competing activities while driving, such as talking on cell phones and to a lesser degree texting [83]. More than half of drivers between the ages of 16 to 34 years fell into the distraction prone category. Neyens and Boyle [84] examined a large database of both minor and serious crashes and found that driver distraction was significantly related to severity of injury for adolescents as both drivers and passengers. Cell phone use was the most hazardous source of distraction, but inattention (defined as looking but failing to see and lost in thought) was the most frequent source of crashes. Nevertheless, although inattention was correlated with occurrence of crashes, it was rarely a source of serious injury. Westlake and Boyle [85] used a questionnaire to study Iowa adolescents in various stages of licensure to determine frequency of engagement in distracting activity. A cluster of youth reporting high engagement in distracting activity while driving (20% of the sample) was found to be more likely to have experienced a crash. Cell phone use was the most frequent source of distraction. These studies confirm that cell phone use is a particularly hazardous source of distraction in adolescents.

Research also indicates considerable individual differences in crash risk in adolescent drivers. The aforementioned study by Westlake and Boyle [85] suggested that a high-risk group of adolescents was most likely to engage in distracting activity while driving and to be at risk for crashing. Similarly, Lucidi et al. [86] found a high risk cluster comprising about a third of their sample of Italian youth that was over-represented by males (75%) and far more likely to have received citations for driving violations. As already noted, female drivers are less likely to have engaged in hazardous maneuvers prior to a crash. These patterns are consistent with research primarily in adults showing that users of cell phones while driving also tend to engage in other high-risk driving practices, such as speeding and frequent lane changing [87,88]. Thus, although cell phone use while driving may place adolescent drivers at great risk, the use of mobile devices while driving may also be more common in youth who exhibit a range of other risk-enhancing behaviors.

Effects of passengers

The effects of peer passengers on adolescent driving have been the subject of considerable research, pointing to both distraction and risk-taking, although the effects are likely dependent on the situation, the driver, and the passengers. A large study of the effects of passengers on crash risk in Sweden found that drivers of all ages (18 years +) were less likely to experience crashes when accompanied by passengers [89]. However, the study did not examine the effects of passenger age. A study of U.S. drivers found an increasing fatal crash risk among drivers ages 16 and 17 years with each additional peer passenger, a result that was not seen in adult drivers [90].

A study of a driving game in which points were awarded for speedy driving found that adolescents (ages 14–18 years) were more likely to favor risky driving practices in the presence of peers than when driving alone [91]. However, adults (ages 24–29 years) exhibited a more conservative shift when driving in the presence of peer observers. The investigators also monitored brain activity while playing the game and found increased activity in the ventral striatum in adolescents, a region that anticipates rewards, but increased activity in frontal lateral regions associated with impulse control in adults. This study was interpreted to show that adolescents are more risky in general in the presence of peers than adults. However, a long line of research shows that effects of groups on risk taking depend on the perceived risk level of other group members, with individuals exhibiting either risky or conservative shifts depending on the perceived riskiness of other group members [92]. Research on the effects of passengers on actual driving behavior appears consistent with this explanation rather than blanket generalizations about adolescent risky driving in the presence of peers.

A recent study using data on fatal crashes and average miles driven by adolescents with and without passengers found that adolescent male drivers ages 16–20 years with male passengers, especially those between the ages of 13 and 34 years, were more likely to experience fatal crashes per miles driven than when driving alone [93]. The effect of female passengers was weaker but still present and appeared to be restricted to younger passengers, ages 13–20 years. In female drivers, the effect of male passengers was smaller but still significant, while the effect of female passengers was somewhat stronger than in male drivers. Thus, there appeared to be a gender similarity effect with drivers and passengers of the same sex experiencing greater fatal crashes than those of opposite sex.

Another study of passenger effects on adolescent drivers ages 16–18 years provided further insight into the mechanisms that underlie the effects of peer passengers ages 14–20 years [94]. This study used data from the NMVCCS and found that male drivers were more likely to engage in aggressive and other unsafe driving practices when driving with passengers. They were also more likely to pay attention to distracting events exterior to the vehicle. Female drivers were only more likely to be distracted by interior activities, such as paying attention to passengers. Thus, the effects of peer passengers appeared to differ by gender with males more likely to engage in overtly risky practices while female drivers were more likely to be distracted by passengers.

There is also some reason to believe that adolescents involved in serious crashes differ from the typical adolescent driver. An experimental study of late adolescents found that risky driving in a simulator increased when peers sent risk-enhancing messages to the driver and decreased when they sent risk-reducing messages [95]. However, under neutral message conditions, drivers tended to be no more risky than when driving alone. Another study found that the presence of a silent peer during simulated driving exercises did not affect the riskiness of driving practices of adolescent drivers [96]. These findings suggest that the effects of peer passengers depend on the risk level of the young driver's friends, a characteristic that may also reflect the risk tendencies of the driver [38].

Similarities between drivers and their passengers may help to explain the findings of a study by Simons-Morton et al. [97] that examined naturalistic driving of 42 newly licensed adolescents (mean age 16.4 years) over a period of 18 months. The study was able to determine crashes and near crashes as a function of passengers of various ages. The study found that the new drivers were most safety conscious when driving with adults but did not differ in driving risk between driving alone versus with teen passengers. However, a measure of perceived riskiness of friends was related to the riskiness of driving when with peer passengers, again suggesting that risk tendencies of drivers may be related to the same characteristic in passengers. Another analysis of the same young drivers by Simons-Morton and colleagues [98] found stable individual differences in risky driving practices that were related to the self-reported risk tendencies of the drivers and their friends.

In sum, the effects of passengers appear to depend on both the age and gender of the driver and passengers. In addition, the riskiness of passengers may affect the riskiness of the driver, with male drivers being more risky on average and male passengers being more likely to encourage risky driving in both male and female drivers. Thus, aggregate crash data may be a reflection of the recklessness of some drivers and their passengers rather than a general characteristic of adolescents. Nevertheless, passengers may also increase opportunities for distraction, especially in female drivers.

Effects of alcohol and other drugs

One of the more startling patterns over the past several decades has been the decline in fatalities attributable to alcohol use by drivers. From 1982 to 2010, the proportion of drivers involved in fatal crashes associated with alcohol use (Blood Alcohol Concentration ≥.01) declined from 60% to 38% [99]. The crash risk in drivers under age 21 years has also declined over that period [100], and reports of driving under the influence of alcohol have declined in adolescents ages 16–17 years from 1999 to 2009 [101]. Furthermore, the proportion of alcohol related fatalities in drivers under the age of 20 years is lower than in drivers ages 20–29 years (20% vs. 39%) [102]. What tends to receive attention with regard to crash rates in adolescents is the higher *relative risk* of driver fatality while under the influence of alcohol for young drivers ages 16–20 years than for older drivers [100]. This effect is likely attributable to the greater interfering effects of alcohol on both motor and attentional skills of novice drivers under the influence of alcohol [103].

Alcohol has been found to reduce the ability to attend to the driving task under divided attention conditions, an effect that should be even more detrimental to novice drivers [104] and to drivers with ADHD [105]. Similar effects have been observed as a result of cannabis use [106]. Indeed, use of both substances increases the risks of driver error, especially inattention, beyond that of either drug alone [106]. There is also evidence to suggest that youth who use multiple drugs, such as alcohol, tobacco, and cannabis are more likely to drive under the influence of alcohol [107] and to experience crashes [48]. This suggests that there may also be individual differences in risk taking associated with drug use that either lead to riskier driving or reduced attention to driving hazards.

Effects of drowsy driving

Drowsy driving is prevalent in the United States, with about 30% of 13- to 18-year-olds in a recent poll reporting having had the experience in the past month [108]. High proportions of adolescents are known to suffer from sleep deprivation likely resulting from diurnal hormonal patterns that encourage staying up late despite school schedules that require early morning attendance [109]. Lack of sleep is clearly linked to deficits in the alerting system [56], and fewer hours of sleep are a risk for increased crash rates in adolescents and young adults [110,111]. A comparison of two matched school districts that differed in high school start times found that the district with later start times had lower student crash rates [112]. Furthermore, school districts that have delayed the beginning of the school day have found reductions in student crashes [113]. Lack of sleep may also affect the attentional capacities of drivers with ADHD, who are more likely to have sleep disturbances [114].

A recent study examined the effects of allowing 14-year-old students to start school an hour later than usual for a 1-week period [115]. Sleep duration was measured using a nighttime activity monitor. Students with the later start time slept an average of 55 minutes longer than a control group with the normal start time. The experimental group also performed better on two tests of sustained attention administered at the end of the school week. The results show that allowing students to sleep longer should enable them to maintain attention to important tasks, such as driving.

Limitations and questions for the future

Our review attempted to cover many factors that affect adolescent driving safety with a particular focus on the effects of brain development and experience on attentional abilities. We believe the findings highlight the value of the model presented in Figure 1 as a way to organize the literature. Nevertheless, an exhaustive review and analysis of the literature was beyond the scope of this effort. More focused reviews of each component of the model could certainly be a project for the future.

Our review suggests a complex interplay between developmental, experience-related, and situational factors that put adolescents at risk for driver distraction, poor situation awareness, and crashes. In addition, individual differences in propensities to experience distractions while driving (e.g., use of cell phones and attention to passengers) or to engage in risky driving practices can exacerbate risks. Policies to lengthen the period of supervised driving before adolescents can achieve full licensure (graduated licenses) are one effective strategy

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to reduce the effects of inexperience. Nevertheless, it is important not simply to rely on natural increases in experience to improve driving skills but also to identify and implement effective training strategies that can better prepare adolescents for competent solo driving [12,116]. Indeed, adolescent novice drivers continue to exhibit reductions in crash risk well past the first 6 months of driving experience [16,17].

Three strategies using computer-based training methods have been developed that should be able to hasten the learning process. These programs (1) educate novice drivers to recognize unexpected hazards, improving the perception and comprehension of situation awareness [34,117]; (2) encourage drivers to act on hazards they already recognize [73,75], improving both comprehension and prediction/planning of situation awareness; and (3) train drivers to limit their time when diverting attention to in-vehicle tasks (e.g., looking at maps) [118], improving all functions of situation awareness. Preliminary evidence from New Zealand suggests that hazard awareness training can be delivered over the Internet [119]. Nevertheless, more research is needed to identify the best ways to deliver these interventions and to determine whether they affect crash rates in the field.

Another important focus for research is to advance our understanding of the difference between age and experience as factors that affect driving risk [17]. Although crash rates decline with experience, they are still higher for novice adolescent drivers (16–19 years) than for novice adult drivers (20 years +) [16,120]. If incomplete developmental maturation limits the ability to learn driving skills, then policies that restrict full licensing to older ages would be justified. It has become boilerplate in discussions about adolescents to note that “brain development is not complete until age 25″ [12,121]. However, little is actually known about the relation between brain development and driving skills. For example, inhibitory attentional and other control skills appear to asymptote much earlier than age 25 years [9,58,59], and large individual differences persist even after reaching this plateau. It is a challenge, therefore, to determine the age at which most adolescents have the requisite brain development to learn how to drive safely, suggesting the need for improved “fitness to drive” licensing policies for novice drivers.

Even if an ideal starting age could be determined, there would be large individual differences in propensities to drive safely. For example, weakness in attentional capabilities such as in ADHD is detrimental to driving safety. Parents may be essential to monitor their adolescent drivers during the training period [122,123]. One approach to enabling parents to extend their supervisory role is the use of in-vehicle video surveillance systems that can provide parents and teen drivers with feedback about their hazardous driving practices [124,125]. This system may even be able to reduce the excess crash risk exhibited by 16-year-old drivers, suggesting that improved parental monitoring of novice drivers can help to reduce the risks associated with early unsafe driving behavior.

Adolescent medicine providers can help parents of higher risk adolescents to be aware of the risk level of their adolescent drivers and give them guidance for how to encourage safer practices in high-risk offspring. Parents of adolescents with attentional and other impulsive tendencies may need to pay greater attention to their children’s training and to invest their time in ensuring that their children receive and complete the training needed to overcome the arduous learning curve needed for safe driving. Learning to drive is an important skill that most adults have mastered. Helping adolescents to achieve the same level of skill without serious consequences is a public health priority that we should all embrace.

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IMPLICATIONS AND CONTRIBUTION

Large individual differences in attentional capabilities as well as risky driving tendencies characterize the novice adolescent driver. However, the research reviewed suggests that significant opportunities exist totrain the skills needed to become a safe driver and that continued research to inform safe driving policy should be a high priority.

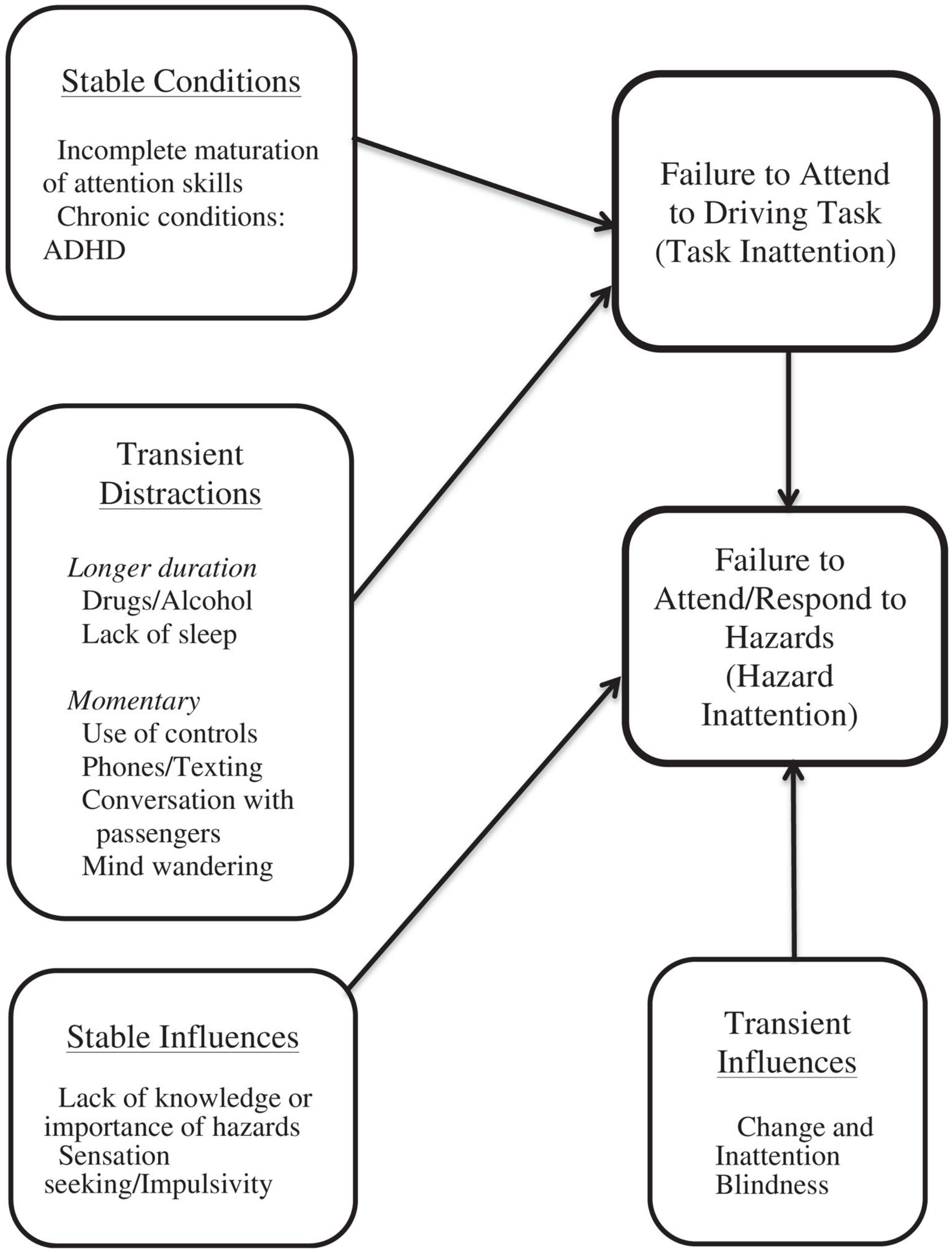

Figure 1.
Model of sources of attention failures in novice drivers.