


Article

# Teen Driving Risk and Prevention: Naturalistic Driving Research Contributions and Challenges

Bruce G. Simons-Morton <sup>1,\*</sup> , Johnathon P. Ehsani <sup>2</sup>, Pnina Gershon <sup>1</sup>, Sheila G. Klauer <sup>3</sup> and Thomas A. Dingus <sup>3</sup>

<sup>1</sup> Health Behavior Branch, Eunice Kennedy Shriver National Institute of Health and Human Development, National Institutes of Health, Bethesda, MD 20892-7000, USA; pnina.gershon@nih.gov

<sup>2</sup> The Johns Hopkins Bloomberg School of Public Health, Baltimore, MD 21205, USA; jpehsani@jhu.edu

<sup>3</sup> Virginia Tech Transportation Institute, Blacksburg, VA 24061, USA; cklauder@vtti.vt.edu (S.G.K.); tdingus@vtti.vt.edu (T.A.D.)

\* Correspondence: mortonb@mail.nih.gov

Received: 26 May 2017; Accepted: 11 December 2017; Published: 18 December 2017

**Abstract:** Naturalistic driving (ND) methods may be particularly useful for research on young driver crash risk. Novices are not safe drivers initially, but tend to improve rapidly, although the pace of learning is highly variable. However, knowledge is lacking about how best to reduce the learning curve and the variability in the development of safe driving judgment. A great deal has been learned from recent naturalistic driving (ND) studies that have included young drivers, providing objective information on the nature of crash risk and the factors that contribute to safety critical events. This research indicates that most learners obtain at least the amount of practice driving recommended and develop important driving skills. Unfortunately, most learners are not exposed during training to more complex driving situations and the instruction provided by supervising parents is mostly reactive and may not fully prepare teens for independent driving. While supervised practice driving is quite safe, crash rates are high during the first six months or so of independent driving then decline rapidly, but remain high for years relative to experienced drivers. Contributing factors to crash risk include exposure, inexperience, elevated gravitational-force event rates, greater willingness to engage in secondary tasks while driving, and social influence from peer passengers. The findings indicate the need and possible objectives for improving practice driving instruction and developing innovative prevention approaches for the first year of independent driving.

**Keywords:** adolescence; risk; learning; safety; attention; distraction; kinematics

## 1. Introduction

Young drivers are at high crash risk relative to older, more experienced drivers [1]. Motor vehicle crashes are the leading cause of death among U.S. adolescents, accounting for approximately a third of all deaths among 16–19-year-old [2]. Novices have particularly high crash rates in the months just after licensure that decline rapidly for about 6 months and/or 1000 miles and then more slowly for years [3–5]. While novices presumably make many judgment errors due to inexperience and young age [6,7], they also experiment with risky driving behaviors [8]. Moreover, relative to older drivers, novices are easily distracted from the driving task [9]. However, many questions remain about the nature of young driver risk, the relative importance of contributing factors, and individual variability in risk [10].

A range of methods can be useful for analyzing the prevalence and variability in crash risk according to driver characteristics and driving conditions. Notably, archival records, mainly based on police reports, provide substantial information about the crash conditions and driver age and sex [1]. These records, however, are limited, particularly with respect to driver behaviors associated

with crashes. Naturalistic driving (ND) methods are uniquely suited to evaluating safety critical events, particularly when sophisticated sensors and cameras are part of the instrumentation. Global Positioning System (GPS), accelerometers, cameras, and other ND sensors can provide objective individual-level information on the safety critical events of crashes and near crashes and the contributing driving conditions and behaviors such as speeding, close following, inattention due to secondary task engagement, and sharp cornering and related elevated gravitational-force events.

The primary limitation of ND research is the generally small volunteer samples in most studies owing to the expense associated with recruiting, instrumenting, and following drivers; and storing, reducing, coding, and analyzing the large amounts of data collected. While naturalistic data are routinely recorded in many vehicles by devices that are either factory-installed or added after-market (sometimes provided by insurance and other proprietary companies), these data are generally not available for independent research purposes. The great advantage of ND is the objective data collected for research purposes over time on crashes and related safety critical incidents and contributing driver behavior and road condition factors. These data can be collected over months or even years on the same individuals. The collection of longitudinal on cohorts provides unique information about how novices learn and the variability within the cohort and over time in driver behavior and risk. When combined with survey and interview data ND methods can provide a wealth of information about crash risk factors that can inform prevention policy and practice. The advantages of ND are not unique to young driver research, but may be particularly relevant to young drivers, given their high crash risk.

Fortunately, some ND studies that have included young drivers have been completed and others are in progress. Here we focus on the most prominent and advanced in terms of completeness of these studies. Collectively, these studies have contributed greatly to our understanding of young driver crash risk. We describe each study briefly and provide key references and notations about purpose, methods, instrumentation, measures, and selected findings. We then draw substantially on the findings from these studies to review what has been learned from naturalistic driving research about young driver crash risk, research gaps, and implications for practice. The paper focuses specifically on the following research questions:

- (1) How and what do novices learn from practice and experience that enables them to reduce crash risk over time?
- (2) What are contributing factors to young driver crash risk, including experience, young age, exposure, distraction, and other risky driving behaviors.

## 2. Naturalistic Driving Studies with Young Drivers

Table 1 summarizes the methods and findings from six major ND driving studies involving young drivers. The first two studies included a focus on supervised practice driving; the others on independent driving.

### 2.1. Practice Driving and Transition to Independent Driving

The purpose of the study was to describe teenage driving behavior and parental instruction provided during the first four months of supervised practice and independent driving [11,12]. Families ( $n = 50$ ) with a teenager learning to drive were recruited and interviewed. Their vehicles were instrumented with DriveCam event recorders and relatively low-threshold triggers were set to capture events of low-to-moderate intensity. Surveys were administered to parents at baseline and throughout the study to complement the ND data. Findings from the surveys and data recorders indicated the following: (1) Parents reported planning to ensure their teen obtained lots of practice, but did not have specific plans and did not access, or were not provided with resources on the topic. (2) Most practice occurred on local roads when traffic was light. (3) Parents and teens quickly gained confidence and triggered events declined rapidly. (4) Few near crashes or similar incidents were noted, although on a few occasions parents alerted the teen to a potential danger. (5) Most instruction focused on vehicle handling and speed; higher order instruction was infrequent. (6) Parent-teen relations were

predominantly civil, with few events of yelling or antagonism. Of the original 50 families, 38 were also assessed during independent driving. The following differences during supervised and independent driving were noted: (1) The proportion of driving during night and inclement weather increased; (2) Loud music played more often; the percentage of trips with a parent declined from 99% to 3%; (3) Solo driving and driving with peers increased from <1% to 62% of clips; (4) The proportion of elevated gravitational force events did not vary; these events were more likely to be attributed to vehicle handling during the learner period and judgment errors during independent driving; (5) A relatively small proportion of the participants was responsible for most of the elevated gravitational-force events.

## 2.2. Supervised Practice Driving Study

The purpose of this study was to examine the amount and nature of practice driving and possible associations with independent driving. The sample consisted of 90 teenagers 16–17 years old with a learner's permit allowing supervised driving and 131 supervising parents. ND data were collected for the entire practice driving period and participants were followed for up to one year after licensure. Vehicles were instrumented with a data acquisition system, including GPS, accelerometers, and cameras; audio recorders were included to capture conversation between supervising parents and their teenage children as they drove [13]. Findings included the following: (1) Teens practiced for an average of 46.6 h; less than half (41 participants) completed the graduated driver licensing (GDL) state requirement of 45 h. (2) Exposure to diverse road types increased over the course of the practice driving period, but average monthly miles of practice driving did not. (3) Parental instruction was primarily focused on the immediate, functional demands of driving, particularly during the initial hours of practice. (4) Few instances of higher order instruction occurred, but increased over time. (5) Driving errors decreased over time. (6) High risk secondary tasks increased over the practice driving period. (7) A small percentage of trips (2.6%) did not have an adult in the front seat, suggesting joy riding, and teens drove in a riskier way during these trips.

## 2.3. 100 Car Study

The 100 Car Study was the first large-scale naturalistic driving study, with 109 vehicles, 241 high-mileage, licensed drivers and were followed for one year [14]. The youngest drivers in the study were 18–20 years old ( $n = 16$ ) Instrumentation included GPS, accelerometers, multiple cameras, machine vision lane tracker, and connection to vehicle network. Over the 2 million miles and 42,000 h of driving, we assessed 16 police-reported crashes, 67 less severe crashes, and 761 near crashes, which were identified and coded for driver behavior and driving conditions. Data were stored in a computer mounted in the trunk of the vehicle and downloaded periodically. Major findings relevant to the youngest drivers included the following: (1) the crash rate was highest for the 18–20-year-old drivers; (2) short headway (time to collision < 2 s) was involved in most rear-end collisions; (3) inattention was observed in most crashes and near crashes; (4) the youngest drivers had the highest rate of aggressive driving behavior, prevalence of secondary task engagement, and distraction-related crashes and near-crashes (CNC) involvement [10,14]. The study demonstrated the unique advantage of ND methods for assessing crash risk due to distracting secondary task engagement by comparing the prevalence of secondary tasks observed in the moments prior to a crash or near-crash (by coders in a laboratory) with the prevalence of those tasks similarly observed during randomly selected baseline road segments. The resulting odds ratios indicated that critical incidents, defined as crashes and near-crashes (CNC) were at least two times higher when the driver was engaging in secondary tasks that took the drivers eyes off the forward roadway for 2 s or longer. The study was the first to demonstrate the advantages of direct and continuous observation of driving behavior for assessing risk due to driver secondary task engagement, drowsiness, and risky driving behaviors such as close following, establishing the utility of the method, and launching the future of ND research.

#### 2.4. Naturalistic Teenage Driving Study (NTDS)

Survey and driving data from a data acquisition system (GPS, accelerometers, cameras) were collected from 42 newly licensed teenage drivers 16–17 years old and their parents during the first 18 months of teenage licensure, allowing comparisons between novice young drivers and their parents driving the same vehicles, mostly over the same roads and driving environment. Findings included the following: (1) Overall, teenage crash and near crash (CNC) rates declined over time, but were >4 times higher among teenagers than adults [4]. (2) Contributing factors to teenage CNC rates included secondary task engagement (e.g., distraction), elevated gravitational force events and rates, low stress responsivity, and risky social norms [15–18]. (3) Notably, there was substantial variability in driver risk behavior, some drivers experiencing no CNC events, others experiencing many [19], although rates did not vary significantly by driver sex. (4) By examining individual trajectories of crash risk over time, approximately half of the drivers have lower risk after 73 h of independent driving after licensure while the risk for others increases [20]. Further examination of the change points for reductions in crash risk indicated that there were three distinct clusters with change-points at 52, 109 and 150 h of driving after first licensure, respectively, with the overall intensity rate and the pattern of change also differing substantially among clusters [20]. Similarly, while young drivers on average had substantially higher elevated gravitational force event rates than adults, one group of young drivers had higher trajectory rates than others [21]. (5) Variability in a stress responsivity test was associated with CNC rates; those not responding to stress normally on a stress test administered early in the study were more likely to be involved in a crash or near crash events over the course of the study, presumably because they did not perceive their driving to be risky or they intentionally engaged in this behavior [17]. The findings support the contention that the high CNC risk among novice teenage drivers is due to inexperience and risky driving behavior, particularly kinematic risky driving (measured as the combination of elevated gravitational-force events per miles driven) and secondary task engagement, with substantial individual variability in risk [15].

#### 2.5. DriveCam Teen Safe Driving Program

The DriveCam in vehicle event recorder (IVER) technology by the company, Lytx (San Diego, CA, USA), includes an accelerometer and cameras that view the driver and forward roadway. DriveCam data are continuously recorded, but only the data proximal in time to events are saved, minimizing storage and coding issues. The events of interest are elevated gravitational forces (collectively termed kinematic risky driving) from erratic driving and evasive maneuvers, which can be coded with respect to potential contributing factors (driver behavior or environmental conditions) for each event. DriveCam is employed mainly as an intervention tool, mostly with fleet vehicles to improve professional driver performance in conjunction with managers who monitor events and provide feedback and consequences. However, this same methodology has been employed with young drivers whose driving can be monitored by their parents (by viewing saved video footage of events over the past week or so) [22]. A substantial number of DriveCam events have been recorded from the long-running Teen Safe Driver Program. Recent analyses of these data that included 400 moderate-to-severe rear-end crashes among teen drivers indicated the following [22]: (1) 75% of events included potentially distracting driver behavior. (2) Cell phone use, attending to a location outside the vehicle, and attending to passengers were the most common secondary task behaviors. (3) Drivers using a cell phone had significantly longer response time than drivers not engaged in any potentially distracting behaviors. (4) In 50% of cases where the driver was using a phone, the driver showed no response to the impending crash compared to 10% where drivers were attending to a passenger.

**Table 1.** Naturalistic driving studies with young driver samples.

| Reference   | Study Name                                | Purpose   | Sample  | Instruments                                  | ND Measures   | Major Findings  |
|---|---|---|---|--|---|---|
| Learner Permit Stage: Supervised Practice Driving   |   |   |   |  |   |   |
| Goodwin, Margolis, Foss, O'Brien, Kirley, 2011 [11]; Goodwin, Foss, Margolis Waller, 2010 [12]; | Practice Driving                          | Evaluate supervised practice driving  | Novices with learner permit ≤ 17 years  | DriveCam accelerometer, two cameras          | Parent & teen communication after low-threshold kinematic events  | Practice Driving<br>(1) Parents lacked practice plans<br>(2) Most practice on local roads, light traffic<br>(3) Events declined rapidly<br>(4) Few safety critical events<br>(5) Instruction mostly functional; little higher order<br>(6) Positive parent-teen relations<br>Independent Driving<br>(1) Night and weather driving increased<br>(2) Parent riding declined (99% to 3%)<br>(3) Solo driving and driving with peers increased <1% to 62%)<br>(4) Kinematic events invariable; few participants accounted for many events |
| Ehsani,Klauer, Zhu, Gershon, Dingus, Simons-Morton, 2017 [13]                                   | Supervised Practice Driving (SPDS)        | Determine the association between practice driving and independent driving outcomes | Novices recruited early after permit and followed up to 12-months post-licensure (n = 80) | DAS: accelerometer, GPS, multiple cameras    | Parent-teen communication during practice diving; exposure, CNC, kinematic events, speeding, impaired driving, secondary task | (1) Average practice = 46.6 h; <50% met GDL requirement of 45 h, 10 h at night;<br>(2) Diversity of practice increased;<br>(3) Mainly functional instruction;<br>(4) Little higher order instruction;<br>(5) Driving errors decreased;<br>(6) High risk secondary tasks doubled over the course of practice<br>(7) No adult in 2.6% of trips with riskier driving   |
| Independent Driving   |   |   |   |  |   |   |
| Dingus, Klauer, Guo, et al., 2002 [14]  | 100 Car                                   | Identify contributing factors to CNC *  | High mileage drivers (n = 100) 18–20 = 16   | DAS: accelerometer, GPS, multiple cameras    | CNC *, kinematic events, speeding, impaired driving, secondary task   | (1) 86% rear-end collisions w/short headway;<br>(2) inattention in 80% of crashes, 65% near crashes;<br>(3) CNC risk 4–6 times greater w/drowsiness;<br>(4) Younger drivers more aggressive, short headway, secondary tasks;<br>(5) NC similar to crashes   |
| Simons-Morton, et al., 2015 [15]  | Naturalistic Teenage Driving Study (NTD5) | CNC * risk during first 18 months of licensure                                      | Novices < 17 at recruitment (n = 42)  | DAS * = accelerometer, GPS, multiple cameras | Rates of CNC *, KR D *, speeding, secondary tasks, skills   | (1) Teen CNC rate >4 times adults'<br>(2) CNC declined over time;<br>(3) CNC contributing factors:<br>a. Secondary task engagement (e.g., distraction),<br>b. Kinematic risky driving;<br>c. Low stress responsiveness;<br>d. Risky social norms  |
| Carney, Harland, McGehee, 2016 [22]   | DriveCam IVER                             | Evaluate driver behaviors proximal to kinematic events                              | Novices <18 years old (n = 412 rear end crashes)  | DriveCam accelerometer, two cameras          | Driver behavior proximal to kinematic events  | (1) secondary tasks in 75% of KR D events;<br>(2) Tasks = phone, outside staring, attending passengers;<br>(3) Phone use increased response time;<br>(4) 50% of events w/phone use—no response to impending crash   |
| Dingus et al., 2016; multiple other [23]  | SHRP2                                     | Identify contributing factors to CNC  | Drivers in multiple age groups (n = 240 novices and ~2600 total)                          | DAS: accelerometer, GPS, multiple cameras    | CNC, kinematic events, speeding, impaired driving, secondary task, many others  | Crash Risk<br>(1) Highest for 16–17-year-old drivers<br>(2) Associated w/high electronic device use;<br>(3) Driver error, fatigue, distraction in ~90% crashes<br>(4) Secondary tasks highest for 16–20, 21–29 y.o.   |

\* Definitions: CNC = crash and near-crash; IVER = in vehicle event recorder; NC = near-crash; KR D = kinematic risky driving; elevated g force events; DAS = Data Acquisition System; GPS = global positioning system.

## 2.6. Strategic Highway Research Program 2 (SHRP 2)

The Second Strategic Highway Research Program (SHRP 2) study is the largest ND study with 3100 study participants aged 16–98 years old, recruited from six regions in the US, and each participant was studied for a period of up to two years. Vehicles were instrumented with a miniaturized version of the Virginia Technical Transportation Institute (VTTI) data acquisition system (MinDAS, which included accelerometers, cameras, GPS, forward radar, and vehicle network connections. Machine-vision software (Center for Technology Development, VTTI, Blacksburg, VA, USA) was used to evaluate lane tracking and driver head position and angle. More than 1500 crashes, including 905 injurious crashes, property damage crashes, and minor collisions were observed. Summarized, de-identified data are available on a website for qualified researchers. Analyses are ongoing, but early findings include the following: (1) High prevalence of handheld electronic device use was associated with crash risk. (2) The prevalence of secondary task engagement was highest for the two youngest age groups (16–20 and 21–29 years) [23,24]. (3) The combination of driver error, fatigue, impairment and distraction was present in nearly 90% of crashes [23]. Research on the data for the youngest driver group, aged 16–17 and mostly recruited within one year of licensure, indicates that crash rates were higher than older more experienced drivers overall and for rear-end collisions (probably reflecting close following, late braking, excess speed, and distraction) [25].

## 3. Risk Factors for Young Driver Crash Risk

### 3.1. Learning to Drive

Driving is a common human activity that, like other complex tasks, must be learned [26,27]. Novice drivers, regardless of age, tend to make many errors [7] and crash at high rates [28]. Fortunately, nearly all drivers eventually learn to drive in a reasonably safe and responsible manner. However, novices have extremely high crash rates relative to older, more experienced drivers and most countries worldwide and each U.S. state requires some form of training before issuing a legal license to drive [28,29], despite the lack of evidence that training is an effective crash prevention measure [27]. Typically, this required training, at least for young novices, takes the form of formal classroom and in-vehicle with a professional instructor or licensed adult. Graduated driver licensing (GDL) policies in the U.S., Canada, Australia, New Zealand, and other countries, supplement formal training by phasing novice teen drivers' exposure to increasingly demanding environments [27,30]. GDL policies require progression through an extended learner license stage, typically requiring a specified number of adult-supervised practice driving hours, and transitions to independent driving with certain limits on the riskiest driving environments (e.g., late night driving, driving with teenage passengers). Where evaluated, the adoption of reasonably strict GDL policies has been shown to reduce crash rates [29].

However, even with GDL policies in place, crash rates are dramatically high in the early months of independent driving [4], particularly in relation to the low crash rates during supervised practice driving [31], and then decline rapidly for a time (roughly 6 to 12 months) and then more gradually over a period of years (until approximately their mid-20s) [5,28]. This deflection in crash risk is consistent with classic learning curves for virtually all complex tasks, where errors are highest initially and then gradually improve with extended practice [27]. It may take only a few hours behind the wheel for most novices to develop reasonable vehicle management skills, but safe driving judgment, as with all complex activities, comes only with experience [27]. Notably, young novices appear to make many errors of judgment and performance [6,7] and apply the skills they have learned mechanically and not contextually [32]. While some unknown portion of novice teen crash risk may be due to deliberate risk taking or simply an absence of accurate risk perception, many crashes are due to mistakes resulting from nonvolitional errors of judgment [6,7]. Hence, there is great interest in determining the best practices for training novices to drive safely [27,29,33].

Despite substantial research it is not clear how much or what type of training is needed to produce safe drivers [27]. Evaluations of driver education and training programs in the U.S., Canada, and other countries have demonstrated no safety benefits, due possibly to the few hours of professional instruction, the emphasis on preparation for successful license testing, or other factors [34]. While novices learn quickly how to manage the vehicle, safe driving judgment takes substantially longer [27]. Possibly, improvements in training might be developed that reduce the length of the learning curve, for example, the current research on hazard mitigation training promises improvements in one important aspect of driving judgment that might eventually work its way into routine driver education practice and provide safety benefits [35]. Similarly, while GDL policies have increased the amount of supervised practice driving novices receive prior to licensure, there is little evidence that increased supervised practice provides safety benefits. Some previous research has focused on the amount teens actually practice, the environments they encounter, and the type of instruction they receive, but this research is sparse and has relied mainly on self-reported measures [36–39]. Therefore, objective ND data are needed as well as prospective trials to demonstrate the efficacy of promising observational studies.

### 3.1.1. Evidence

ND methods allow for direct observation of how much practice driving occurs, where and when it happens, and the verbal interactions between the adult supervisor and teenage driver. The two recent naturalistic studies on supervised practice driving have extended our understanding of how parents provide instruction and the type of errors that teens make during practice and early independent driving [11,12]. Both studies document that parents provide substantial hours of supervision as teens are learning to drive, if not always as much as the GDL requirement. Instruction is largely unplanned and focused on functional driving matters, with little higher-order instruction (defined as instruction that generalizes learning from a specific event or scenario to more general cases or situations), and almost no emphasis on parental expectations for teen independent driving. The amount and complexity of practice driving do not increase uniformly over the practice-driving period as would be expected. Safety critical events during practice driving appear to be rare and errors decline over the practice driving period. It seems that learning occurs during the training and practice driving period, but to date there is no evidence that this training translates into safe independent driving [27,33].

### 3.1.2. Research Gaps

Given the paucity of research on the learner period, substantial research is needed to gain a better understanding of the nature and value of training and practice driving and how to improve its value consistent with independent driving safety. ND research is particularly needed on the following topics: (1) Why is practice driving relatively safe, but early independent driving highly dangerous? Is it mainly because training is inadequate or because some novices fail to learn or are inherently risk-prone? (2) How can we measure learning to drive safely? Changes in crashes and related safety critical events provide objective information about learning, but these events are relatively rare, and vary according to the demands placed on or assumed by the driver. The complexity of driving exposure generally increases as novices gain experience and drive more often in heavy traffic, at night, during inclement weather, with multiple passengers, while engaging in secondary tasks and these more demanding traffic conditions require greater attention and better judgment. Presently, there are few objective measures of driving skill/judgment that can be used to assess improvements over time in safe driving behavior. (3) How do professional driving instructors and supervising parents teach their children to drive? Do those who supervise novices provide the type of instruction required for learning, including rigorous and progressively more complicated practice, feedback, higher order attentional skills, self-management, and purposeful safe driving attitudes? Do supervisors co-drive beyond that which is necessary for safety and to the extent the novice does not experience full responsibility during the practice driving/learner period, thereby preventing the development prior to licensure of

safe driving judgment [27]? While co-driving in the form of telling the driver what to do, preparing them for impending maneuvers, warning them about hazards, navigating, limiting secondary task engagement, and managing passengers is reasonable behavior for those responsible for maintaining the safety of learners; novices will be responsible for them as soon as they begin to drive independently without a supervisor. (4) Is the amount, type, and quality of training and practice driving associated with independent driving outcomes? Would more and better training and practice improve safety? More detailed examinations are needed of the possible associations between the variability in the amount, diversity, and quality of practice driving and independent driving outcomes such as CNC, secondary task engagement, speeding, and kinematic risky driving rates.

### 3.2. Exposure

Notably, the more one drives the greater the absolute risk for crashing, but the more one drives the lower the crash rate [40]. This is true of all drivers, but particularly for novices, who experience very high crash rates during the first months and years of driving, which decline as drivers gain experience [28]. In one study, novices with the most crashes the first year of licensure also drove the most and had the highest rate of crashes/miles driven [4]. Therefore, it makes sense to limit the amount that novices drive during at least the first months or year of independent driving while they are still developing basic safe driving judgment [27]. The idea is to encourage substantial amounts of relatively low-risk driving before gradually exposing novices to more risky driving situations. Clearly not all experience is equally risky. Hence, modern licensing policy in the form of GDL seeks to limit novice teen driving under the most dangerous driving conditions, for example, at night, with multiple passengers, and when impaired or distracted due to secondary task engagement [29,41]. Furthermore, parents are encouraged to limit teen driving further, including both high-risk conditions and the total amount of driving while the teenager gains experience under more routine driving conditions [42].

In addition to the relationship between the amount of driving and crash risk, accurate assessment of exposure is important for comparing crash risk across groups by age, sex, and other characteristics and identifying the key contributing factors for these groups. Information on crash events, the numerator in a crash rate, is available from a variety of crash databases, often created from police reports, but these sources do not generally include all crashes and seldom include estimates of exposure. The best measure of exposure is miles or hours driven over the period or under the conditions of interest, data that are only readily available in ND studies with GPS included.

In the absence of objective mileage, data researchers employ alternative population-based metrics such as number of licensed drivers, which can provide estimates of crash rates [43]. Also, individual-level data on exposure are available in survey research, including from the National Household Travel Survey [44], but self-reported trips and miles traveled is not entirely reliable [45]. The lack of objective driving exposure data in the United States and internationally is a widely-accepted problem [46]. Notably, the lack of objective driving exposure data limits the calculation of rates that can be used to examine changes in risk among young drivers over time, given the rapid changes in rates over time and the need to measure the practical goal of reducing the amount of time required for crash rates to reach adult levels. Hence, objective measures of exposure assessed at an individual level can improve precision and assessment of contributing factors [46].

Naturalistic driving studies with Global Positioning System (GPS) technology measure driving exposure at the individual level using metrics such as miles or vehicle hours traveled for each trip and can be summarized for various periods (e.g., month, quarter, year). While GPS data are highly accurate, there can be brief delays after ignition before GPS satellite connection and there are occasional road segments where GPS is unreliable, so ND researchers combine GPS data with data from the vehicle On-Board Diagnostic port for data on exposure and speeding [47]. When camera measures are also included, exposure can be specified according to individual driver, road conditions, weather, passenger presence, and safety critical events such as crashes and near crashes.



### 3.2.1. Evidence

Naturalistic driving data from 42 teenage participants in the NTDS indicated considerable variability in overall exposure during the first year of driving, some driving less than 2000 miles during the first 12 month of licensure and others over 5000 miles [47]. Relative to their parents, novice teens drove more frequently in higher risk conditions such as at night. While teens generally drove alone, seldom with a parent or other adult, and infrequently with more than one teenage passenger, those with primary vehicle access drove more than other teens, particularly at night, with multiple teen passengers present, and more of the time 10 MPH above the speed limit [15,48]. Crash rates were highest when teens drove alone, and lowest when they drove with a parent, somewhat lower with a teen passenger than when driving alone, higher during the day than at night [18,47] and higher when engaging in certain secondary tasks [9].

### 3.2.2. Research Gaps

Additional research on young driver exposure with larger sample sizes is needed that would provide information on the following topics: (1) What is the safest balance between maximizing experience leading to improved driving and minimizing exposure that increases crash risk? Are crash rates higher among young drivers who drive more the first year of licensure relative to those who drive less and among those who experience relative greater or lesser range of driving experience? To the extent crash risk varies according to mileage, is this due to the nature of driving conditions or how aggressively or carefully these miles were driven? Possibly, drivers conform to risk adaptation, where they select more complicated driving contexts and demands and take more risk as they develop or perceive that they have developed greater skill, which would logically occur with respect to any complex task, but it is unclear the extent of such risk adaptation, and there is little evidence for the proposition that risk adaptation is responsible for young driver crash risk. Alternatively, some drivers appear to learn quickly from their negative driving experiences, for example, reducing speed and increasing following distance after experiencing a safety critical event, but some do not. For example, in the NTDS, some teens had persistently low crash/near crash rates, others had persistently high crash rates, while some had high rates over the first six months that declined rapidly thereafter, consistent with learning from experience [19,20]. (2) Do certain factors increase risk more under certain driving conditions? For example, are teenage passengers more distracting and risk provoking when the driving destination is a social event or late at night? Are novice teens more likely to speed on familiar roads (just for the fun of it) or on unfamiliar roads (because they don't know the speed limit or don't understand the risk)? Is secondary task engagement among novices more or less frequent and dangerous when driving with passengers and to what extent do young drivers adapt their secondary tasking to driving conditions?

Emerging technologies that calculate mileage using vehicle-based or wireless technologies could potentially be incorporated to better collect objective driving exposure data to allow for better evaluation of how various contributing factors impact crash risk for teen drivers. GPS data also represent an opportunity to explore the geospatial characteristics of teenage driving behavior, both during the practice or independent driving stages, though little research has been done to examine how driving risk varies as a function of the spatial characteristics individual drivers.

### 3.3. Distraction

Distracted driving is the diversion of driver attention from the primary driving task, often when engaging in a task secondary to driving, although inattention to the driving task can also occur due to impairment from drugs, drowsiness, or fixation on objects and activities outside the vehicle [22]. Distraction due to secondary task engagement is a particular problem for young drivers compared to other driver age groups [9,49–52]. Teenage drivers 15–19 years old have the highest rate of distraction-related fatal crashes of all other age groups [49]. With the rapid development of

in-vehicle infotainment technologies, increased functionality of portable electronic devices, and the tendency of teenagers to be early adopters of new technologies [50] distraction due to secondary task engagement can be expected to increase.

Research on distracted driving has included archival records, self-reports, retrospective tools, driving simulators, and closed driving tracks. Recent ND methods make it possible to objectively examine driving performance and secondary task engagement, and to collect detailed information on the driver's state and driving environment. In ND studies, secondary tasks are identified by coders viewing video footage of the driver and vehicle interior and exterior. The vast amount of data collected is reduced to the few seconds before and after safety critical events, usually crashes and near crashes, and then coded. Additionally, a random sample of road segments is generally used to generate a sample of "usual" or "normal" driving data, which is coded in the same manner as the event data. The prevalence of secondary tasks during critical events can then be compared with the prevalence of task engagement during "usual" driving, providing odds ratios that indicate the likelihood of a safety critical event. Various studies have grouped secondary tasks according to the complexity, sensory input, cognitive demand, or control characteristics (e.g., visual, auditory, cognitive, biomechanical etc. [52,53]).

### 3.3.1. Evidence

Overall, ND studies show that teen drivers compared to older drivers engage more often in secondary tasks and have greater crash risk due to secondary task engagement [9,52,54]. In the SPDS, at least one secondary task was observed in 58% of randomly-selected noncrash road segments [54]. The NTDS indicated that several types of secondary tasks were associated with CNC among novice young drivers, while only phone dialing was associated with CNC among adult drivers [9]. Gershon and colleagues [54] found that high-risk secondary tasks accounted for 21% of tasks while driving, and task engagement varied according to driving conditions, vehicle occupancy, and social norms. Using an event triggered dataset, Carney et al. [22] found that 76% of rear-end crashes were associated with some type of secondary task engagement. Previous studies found that dialing and texting, reaching for an object, consuming food, and attending to external distraction were highly associated with safety critical events among teenage drivers [9,52]. While passenger presence appears to moderate teens' tendency to engage in secondary tasks [54], novice teens with primary rather than shared vehicle access were more likely to engage in a secondary task while driving [54]. Finally, secondary tasks with relatively greater cognitive load and long eye glances away from the forward roadway were associated with safety critical event likelihood [55].

### 3.3.2. Research Gaps

Engaging in secondary tasks is highly prevalent across all driver age groups and certain high-demand tasks are associated with crash risk, particularly among teen drivers. A great deal of research and policy attention has been directed recently at distracted driving among novice and experienced drivers. However, many questions remain and improved research methods are needed, including the following: (1) To what extent is the association between crash risk and secondary task engagement among young drivers due to increased duration of eyes off road (which is clearly associated with crash risk among drivers off all ages) [23], inability to handle and divide attention to competing, highly-demanding tasks (e.g., driving and texting), and lack of judgment regarding the safety envelope needed to engage in a secondary task relatively safely? (2) Would comparisons across ND studies be facilitated through more systematic coding and consistent classification of secondary tasks based on demand or complexity and duration of engagement? (3) Given the unequal distribution of secondary tasks across drives, time of day, and driving conditions, would extensive, systematic sampling of noncritical event "baseline" sample road segments, as developed for the SHRP2, improve the accuracy of secondary task prevalence and risk estimates? (3) Can advanced vehicle technology

reduce distraction? Technology is in development that eventually will be able to detect when the driver's eyes are off the forward roadway and provide a warning to the driver.

### 3.4. Kinematic Risky Driving

Aggressive and erratic driving is an established safety concern, kinematic risky driving is a risk factor that unique to teen drivers, particularly novices. It is not uncommon to see a driver tailgate, change lanes suddenly, drive too fast for conditions, weave through traffic, brake at the last moment, speed away from a stop, and make sharp turns. However, the prevalence of such risky driving has been difficult to quantify, although there is considerable variability when measured by self-report [56], suggesting that some teenagers drive frequently in a risky manner. ND methods allow objective quantitative assessment of risky driving through measures of speeding, observed close following and time to collision metrics, from lateral and longitudinal linear accelerations and from angular accelerations. Accelerometers assess gravitation forces in multiple dimensions, generally longitudinal acceleration in hard starts and merges, longitudinal deceleration in sharp braking, lateral acceleration in turns, and yaw in overcorrection maneuvers [4]. Here we focus on acceleration data because thresholds can be established that indicate unusually risky driving behaviors. When a threshold is exceeded, the event can be automatically recorded; events from all dimensions can be combined to form the numerator of an event rate, with the denominator based on GPS data on miles driven. The resulting measure of elevated g-force event rates is commonly referred to as kinematic risky driving (KRD).

Research evidence indicates that KRD rates are much higher on average among young drivers than older, more experienced drivers [18]. Indeed, reductions in driving behaviors that trigger kinematic events among young drivers is the focus of the DriveCam-based American Family Teen Driver Safety Program [22], and other, similar programs [57]. These programs link each KRD event to feedback to the driver in the form of a blinking light and/or sound, and in most cases, a record of the event, in the form of video when available, is saved and made available to the participating teens and their parents. Evaluations of these programs have demonstrated that this feedback to teens and parents is associated with rapid declines in KRD rates and presumably improved safety, although the programs have been too small to demonstrate crash reductions. In one randomized trial, DriveCam devices were installed in the vehicles of young drivers and set on "stealth" mode for a month [8]. Then, in one group, the light was activated so the driver was informed by a blinking light when an event occurred. In the other group the light was activated and the drivers were informed that their event score and videos of each event would be available for them and their parents to view. Those in the first group with feedback to the driver only did not change their KRD behavior over time, while those with feedback to driver and parents significantly reduced their rate of KRD immediately after the light was turned on. This suggests that at least for young drivers, potential parental consequences reduce average KRD behavior. Of note, feedback to the driver did not change behavior, presumably because events were not linked to possible negative consequences.

While researchers have used a variety of lateral and longitudinal dimensions and g-force cut points to operationalize KRD, in general thresholds of 0.30-0.50 g-forces for each dimension seem most useful as measures of risky kinematic events. At these thresholds events are frequent enough for analyses, uniformly associated with driver behavior (and not simply rough roads or the like), and uncomfortable to passengers [4]. Generally, the events are combined into a single measure of KRD, but at times only hard braking or sharp turns are analyzed.

#### 3.4.1. Evidence

In the NTDS, KRD rates were higher on average among young drivers than their parents driving the same vehicles on the same roads [4]. Rates were highly variable among and between teen participants, did not decline on average, but were higher in a group composed of about 1/3 of the sample and lower among the others [16]. KRD rate was correlated with CNC rate ( $r = 0.60$ ).

Moreover, in prediction analyses monthly KRD rates predicted the likelihood of a CNC the following month, with 0.76 area under the curve, reflecting high sensitivity and specificity [16]. The primary psycho-social factor associated with higher KRD rates is perceived social norms favoring risky driving behavior [18]. As noted KRD declines when feedback is provided to both young drivers and their parents [8,22]. Using SHRP-2 data on 17–18-year-old drivers [58], it was reported that KRD declined after a crash (police-reportable severity), suggesting that teens moderated their driving behavior in response to crashing. The research suggests that KRD is a unique risk factor for young drivers, given the dramatically higher rate of KRD among novices than adult drivers in all studies where it has been measured.

### 3.4.2. Research Gap

KRD is a unique risk factor for young drivers, who have high rates relative to older drivers. However, KRD rates over time have been evaluated carefully in only a few studies and the need for replication is great. Research questions that would advance understanding of this important area include: (1) What dimensions should be included in composite measures of KRD and what thresholds are best associated with crash likelihood? (2) What individual factors best characterize KRD? There is considerable individual variability in KRD rates, but the characteristics of the variability in this behavior are not well studied. (3) Could the findings of O'Brien and colleagues [58] that reported declines in KRD after a crash be replicated with other samples of young drivers and with older drivers? (4) Would reductions in KRD rates improve crash outcomes? (5) Is it possible to employ smart phone accelerometers to obtain information on KRD rates from large numbers of young drivers and possibly provide feedback about driving behavior using this technology?

## 4. Discussion and Conclusions

A great deal has been learned in the past decade about young driver risk from studies employing a wide range of methods and designs. Naturalistic driver studies have figured prominently in this research. ND data have sometimes been combined with data from the same study participants from surveys, test track studies, and simulation. ND research has the potential to objectively assess over time a variety of outcomes, including exposure, safety critical events, and contributing factors. With many ND studies underway that include with young driver samples, a great deal more will be learned in the near future.

### 4.1. Research Questions

We have based this paper on the findings from the few completed or nearly completed ND studies with young driver samples with respect to two primary questions.

- (1) How and what do novices learn that enables them to reduce crash risk over time as they gain driving experience?

It has long been known that novices have high crash rates early in licensure that decline over time. We have learned from ND studies that this risk is not uniform, with some young drivers experiencing few or no safety critical events, while others experience many; some improving over time, but others remaining at high risk for at least 18 months. Supervised practice driving does not seem to be planned and orderly, and does not generally conform to principles of learning, where practice increases in complexity over time and substantive corrective feedback and generalization to future driving contexts. Nonetheless, driving errors appear to decline with practice, suggesting some learning occurs. Curiously, novices appear to develop the ability to drive in a relatively safe manner, but on their own, many of them do not exercise safe driving judgment, engaging in distracting secondary tasks and generating high KRD rates. So, we don't really know how novices develop safe driving judgment, why a large portion of novices have no crashes and engage in little risky driving behavior,

while others engage in high levels of risky driving and have multiple critical incidents the first year of independent driving. Moreover, we know little about how best to teach teenagers to drive safely.

(2) What are the contributing factors to young driver crash risk?

ND research has uniquely contributed to the findings on contributing factors to novice teenage driving risk beyond the established research on inexperience and young age. Notably, exposure to higher risk driving conditions varies considerably and the more novice teens drive the greater their risk of crashing. Novices make many errors of performance and judgment. Among young drivers the risk of a critical incident is highly associated with secondary task engagement, particularly those that take drivers' eyes off the forward roadway for prolonged periods. KRD is a unique young driver risk factor, as rates are relatively low among experienced adults, but relatively high among novices and highly associated with critical incidents. KRD can be reduced when parents monitor this behavior.

#### 4.2. Limitations

Findings on the probable contributing factors of speeding and passenger presence were not presented due to space limitations and limited naturalistic data on these topics. Impairment due to substance use and drowsiness is a serious concern, but relatively rare among novices and not reported here. Too few ND studies have been conducted with novice young drivers to enable meta-analyses of crash contributing factors. Given the generally small, volunteer study populations and rarity of crashes, ND studies have mainly assessed nonfatal and lower severity crashes, which may not be fully representative of serious or fatal crashes of the general population of drivers. Moreover, some safety critical events may go undiscovered and unreported in ND studies, although machine learning methods may eventually reduce missed events. Finally, driver behavior may be influenced by the presence in the vehicle of cameras and other instruments, although in post-study interviews participants reported only minor and sporadic awareness of the instrumentation [59].

#### 4.3. Conclusions

ND research indicates that most learners obtain at least the amount of practice driving recommended and novices develop important driving skills, but most learners gain limited exposure to more complex driving situations and the instruction provided by supervising parents is mostly functional, with little higher-order instruction. While supervised practice driving is quite safe, it does not appear to protect novices from independent driving crash risk. Contributing factors to young driver independent driving crash risk include inexperience, exposure, elevated gravitational-force event rates, and secondary task engagement. There is considerable variability in independent driving outcomes typified by risky driving norms and low response to stress. The findings across ND studies indicate the need to improve parent supervised practice driving instruction and confirm the goal of GDL to reduce exposure to high risk driving conditions as novices develop skill and judgement as possible ways to reduce teenage risky independent driving behavior.

**Acknowledgments:** This research was supported by the intramural program of the NICHD, HD001707. No funds from this source were used to cover the costs to publish in open access.

**Author Contributions:** Bruce G. Simons-Morton, Johnathon P. Ehsani, and Sheila G. Klauer conceptualized the work. Bruce G. Simons-Morton, Johnathon P. Ehsani, Pnina Gershon, Sheila G. Klauer, and Thomas A. Dingus prepared the manuscript, and all reviewed and commented on drafts and approved the final manuscript.

**Conflicts of Interest:** The authors have no conflicts of interest related to this manuscript or the research upon which it was based.

## Abbreviations

|       |  |
|-------|--|
| DAS   | Data acquisition system                                      |
| CNC   | Crashes or Near Crashes                                      |
| IVER  | In-vehicle event recorder                                    |
| GDL   | Graduated Driver Licensing                                   |
| GPS   | Global positioning system                                    |
| KRD   | Kinematic Risky Driving; elevated gravitational force events |
| NHTSA | National Highway Traffic Safety Administration               |

## References

1. National Highway Traffic Safety Administration. Young Drivers. DOT HS 812 019. Available online: <https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812019> (accessed on 12 May 2017).
2. Centers for Disease Control. Motor Vehicle Occupant Death Rate, by Age and Gender, 2012 & 2013. Available online: <https://data.cdc.gov/Motor-Vehicle/Motor-Vehicle-Occupant-Death-Rate-by-Age-and-Gende/rqg5-mkef> (accessed on 12 May 2017).
3. McCartt, A.T.; Shabanova, V.I.; Leaf, W.A. Driving experience, crashes, and traffic citations of teenage beginning drivers. *Accid. Anal. Prev.* **2003**, *35*, 311–320. [[CrossRef](#)]
4. Simons-Morton, B.G.; Ouimet, M.C.; Zhang, Z.; Lee, S.L.; Klauer, S.E.; Wang, J.; Chen, R.; Albert, P.E.; Dingus, T.E. Crash and risky driving involvement among novice adolescent drivers and their parents. *Am. J. Public Health* **2011**, *101*, 2362–2367. [[CrossRef](#)] [[PubMed](#)]
5. Williams, A.F. Teenage drivers: Patterns of risk. *J. Saf. Res.* **2003**, *34*, 5–15. [[CrossRef](#)]
6. McKnight, J.A.; McKnight, S.A. Young novice drivers: Careless or clueless? *Accid. Anal. Prev.* **2003**, *35*, 921–925. [[CrossRef](#)]
7. Curry, A.E.; Hafetz, L.; Kallan, M.J.; Winston, F.K.; Durbin, D.R. Prevalence of teen driver errors leading to serious motor vehicle crashes. *Accid. Anal. Prev.* **2011**, *43*, 1285–1290. [[CrossRef](#)] [[PubMed](#)]
8. Simons-Morton, B.G.; Bingham, C.R.; Ouimet, M.C.; Pradhan, A.K.; Chen, R.; Barretto, A.; Shope, J.T. The effect on teenage risky driving of feedback from a safety monitoring system: A randomized controlled trial. *J. Adolesc. Health* **2013**, *53*, 21–26. [[CrossRef](#)] [[PubMed](#)]
9. Klauer, S.G.; Guo, F.; Simons-Morton, B.G.; Ouimet, M.C.; Lee, S.E.; Dingus, T.A. Distracted driving and risk of road crashes among novice and experienced drivers. *N. Engl. J. Med.* **2013**, *370*, 54–59. [[CrossRef](#)] [[PubMed](#)]
10. Klauer, S.G.; Dingus, T.A.; Neale, V.L.; Sudweeks, J.D.; Ramsey, D.J. Comparing Real-World Behaviors of Drivers with High Versus Low Rates of Crashes and Near-Crashes. DOT HS 811 091. Available online: <http://www.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/2009/811091.pdf> (accessed on 12 May 2017).
11. Goodwin, A.; Margolis, L.H.; Foss, R.; O'Brien, N.; Kirley, B. Improving Parental Supervision of Novice Drivers Using an Evidence-Based Approach. AAA Foundation, August 2013. Available online: <https://www.aaafoundation.org/sites/default/files/Parent%20Coaching%20Executive%20Summary%20FINAL.pdf> (accessed on 9 May 2017).
12. Goodwin, A.; Foss, R.; Margolis, L.; Waller, M. Parents, Teens and the Learner Stage of Graduated Driver Licensing. 2010. Available online: <https://www.aaafoundation.org/sites/default/files/ParentsTeensReport.pdf> (accessed on 12 May 2017).
13. Ehsani, J.; Klauer, S.; Zhu, C.; Gershon, P.; Dingus, T.; Simons-Morton, B. Naturalistic assessment of the learner license period. *Accid. Anal. Prev.* **2017**, *106*, 275–284. [[CrossRef](#)] [[PubMed](#)]
14. Dingus, T.A.; Klauer, S.G.; Neal, V.L.; Petersen, A.; Lee, S.E.; Sudweeks, J.D.; Perez, M.A.; Hankey, J.; Ramsey, D.J.; Gupta, S.; et al. The 100-Car Naturalistic Driving Study. Phase II—Results of the 100-Car Field Experiment. 2002; DOT HS 810 593. Available online: <https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/100carmain.pdf> (accessed on 12 May 2017).
15. Simons-Morton, B.G.; Klauer, S.G.; Ouimet, M.C.; Guo, F.; Albert, P.S.; Lee, S.E.; Ehsani, J.P.; Pradhan, A.K.; Dingus, T.A. Naturalistic Teenage Driving Study: Findings and lessons learned. *J. Saf. Res.* **2015**, *54*, 41–44. [[CrossRef](#)] [[PubMed](#)]
16. Simons-Morton, B.G.; Zhang, Z.; Jackson, J.C.; Albert, P.S. Do Elevated Gravitational-Force Events While Driving Predict Crashes and Near Crashes? *Am. J. Epidemiol.* **2012**, *175*, 1075–1079. [[CrossRef](#)] [[PubMed](#)]

17. Ouimet, M.C.; Brown, T.G.; Guo, F.; Klauer, S.G.; Simons-Morton, B.G.; Fang, Y.; Lee, S.E.; Gianoulakis, C.; Dingus, T.A. Higher crash and near-crash rates in teenaged drivers with lower cortisol response: An 18-month longitudinal, naturalistic study. *JAMA Pediatr.* **2014**, *168*, 517–522. [[CrossRef](#)] [[PubMed](#)]
18. Simons-Morton, B.G.; Ouimet, M.C.; Zhang, Z.; Lee, S.L.; Klauer, S.E.; Wang, J.; Chen, R.; Albert, P.; Dingus, T.E. The effect of passengers and risk-taking friends on risky driving and crashes/near crashes among novice teenagers. *J. Adolesc. Health* **2011**, *49*, 587–593. [[CrossRef](#)] [[PubMed](#)]
19. Guo, F.; Simons-Morton, B.G.; Klauer, S.G.; Ouimet, M.C.; Dingus, T.A.; Lee, S.E. Variability in crash and near-crash risk among novice teenage drivers: A naturalistic study. *J. Pediatr.* **2013**, *163*, 1670–1676. [[CrossRef](#)] [[PubMed](#)]
20. Li, Q.; Guo, F.; Klauer, S.G.; Simons-Morton, B.G. Evaluation of risk change-point for novice teenage drivers. *Accid. Anal. Prev.* **2017**, *108*, 139–146. [[CrossRef](#)] [[PubMed](#)]
21. Simons-Morton, B.G.; Cheon, K.; Guo, F.; Albert, P. Trajectories of kinematic risky driving among novice teenagers. *Accid. Anal. Prev.* **2012**, *51*, 27–32. [[CrossRef](#)] [[PubMed](#)]
22. Carney, C.; Harland, K.K.; McGehee, D.V. Using event-triggered naturalistic data to examine the prevalence of teen driver distractions in rear-end crashes. *J. Saf. Res.* **2016**, *57*, 47–52. [[CrossRef](#)] [[PubMed](#)]
23. Dingus, T.A.; Guo, F.; Lee, S.; Antin, J.F.; Perez, M.; Buchanan-King, M.; Hankey, J. Driver crash risk factors and prevalence evaluation using naturalistic driving data. *Proc. Natl. Acad. Sci. USA* **2016**, *113*, 2636–2641. [[CrossRef](#)] [[PubMed](#)]
24. Guo, F.; Klauer, S.G.; Fang, Y.; Hankey, J.M.; Antin, J.F.; Perez, M.A.; Lee, S.E.; Dingus, T.A. The effects of age on crash risk associated with driver distraction. *Int. J. Epidemiol.* **2017**, *46*, 258–265. [[CrossRef](#)] [[PubMed](#)]
25. Seacrist, T.; Belwadi, A.; Prabahar, A.; Chamberalin, S.; Megariotis, J.; Loeb, H. Comparison of crash rates and rear-end striking crashes among novice teens and experienced adults using the SHRP2 Naturalistic Driving Study. *Traffic Inj. Prev.* **2016**, *17*, 48–52. [[CrossRef](#)] [[PubMed](#)]
26. Fitts, P.M.; Posner, M.I. *Human Performance*; Brooks/Cole Publishing Company: Belmont, CA, USA, 1967.
27. Simons-Morton, B.; Ehsani, J.P. Learning to drive safely: Reasonable expectations and future directions for the learner period. *Safety* **2016**, *2*, 20. [[CrossRef](#)] [[PubMed](#)]
28. Twisk, D.A.; Stacey, C. Trends in young driver risk and countermeasures in European countries. *J. Saf. Res.* **2007**, *38*, 245–257. [[CrossRef](#)] [[PubMed](#)]
29. Williams, A.F.; Tefft, B.C.; Grabowski, J.G. Graduated driver licensing research, 2010–present. *J. Saf. Res.* **2012**, *43*, 195–203. [[CrossRef](#)] [[PubMed](#)]
30. Johnson, S.B.; Jones, V.C. Adolescent development and risk of injury: Using developmental science to improve interventions. *Inj. Prev.* **2011**, *17*, 50–54. [[CrossRef](#)] [[PubMed](#)]
31. Mayhew, D.R.; Simpson, H.M.; Pak, A. Changes in collision rates among novice drivers during the first months of driving. *Accid. Anal. Prev.* **2003**, *35*, 683–691. [[CrossRef](#)]
32. Pradhan, A.K.; Li, K.; Ehsani, J.P.; Ouimet, M.C.; Klauer, S.G.; Simons-Morton, B.G. Measuring Young Drivers' Behaviors during Complex Driving Situations. In Proceedings of the 7th International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, Bolton Landing, NY, USA, 17–20 June 2013.
33. Foss, R.D.; Masten, S.V.; Godwin, A.H.; O'Brien, N.P. The Role of Supervised Driving Requirements in Graduated Driver Licensing Programs. DOT HS 811 550. Available online: <https://pdfs.semanticscholar.org/5186/b1fa5f5c6db71aca750d259557c25d03e076.pdf> (accessed on 18 May 2017).
34. Lonero, L.; Mayhew, D. Large-Scale Evaluation of Driver Education: Review of the Literature Driver Education Evaluation, 2010 Update. Available online: <https://www.aaafoundation.org/sites/default/files/LSEDElitReview.pdf> (accessed on 12 May 2017).
35. Chan, E.; Pradhan, A.K.; Pollatsek, A.; Knodler, M.A.; Fisher, D.L. Are driving simulators effective tools for evaluating novice drivers' hazard anticipation, speed management, and attention maintenance skills? *Transp. Res. Part F Traffic Psychol. Behav.* **2010**, *13*, 343–353. [[CrossRef](#)] [[PubMed](#)]
36. Bates, L.; Watson, B.; King, M.J. The role of parents and non-parents in the supervision of learner drivers in Australia. *Accid. Anal. Prev.* **2014**, *70*, 40–45. [[CrossRef](#)] [[PubMed](#)]
37. Jacobsohn, L.; García-España, J.F.; Durbin, D.R.; Erkoboni, D.; Winston, F.K. Adult-supervised practice driving for adolescent learners: The current state and directions for interventions. *J. Saf. Res.* **2012**, *43*, 21–28. [[CrossRef](#)] [[PubMed](#)]

38. McCartt, A.T.; Hellinga, L.A.; Haire, E.M. Age of licensure and monitoring teenagers' driving: Survey of parents of novice teenage drivers. *J. Saf. Res.* **2007**, *38*, 697–706. [[CrossRef](#)] [[PubMed](#)]
39. Staplin, L.; Gish, K.W.; Joyce, J. 'Low mileage bias' and related policy implications—A cautionary note. *Accid. Anal. Prev.* **2008**, *40*, 1249–1252. [[CrossRef](#)] [[PubMed](#)]
40. Elvik, R. Laws of accident causation. *Accid. Anal. Prev.* **2006**, *38*, 742–747. [[CrossRef](#)] [[PubMed](#)]
41. Foss, R.D.; Goodwin, A.H. Distracted driver behaviors and distracting conditions among adolescent drivers: Findings from a naturalistic driving study. *J. Adolesc. Health* **2014**, *54*, S50–S60. [[CrossRef](#)] [[PubMed](#)]
42. Simons-Morton, B.G.; Ouimet, M.C. Parent involvement and novice teen driving: A review of the literature. *Inj. Prev.* **2006**, *12*, i30–i37. [[CrossRef](#)] [[PubMed](#)]
43. Shope, J.T.; Bingham, C.R. Teen driving: Motor-vehicle crashes and factors that contribute. *Am. J. Prev. Med.* **2008**, *35*, S261–S271. [[CrossRef](#)] [[PubMed](#)]
44. United States Department of Transportation. National Household Travel Survey. Available online: <https://www.nationalhouseholdtravelsurvey.com> (accessed on 12 May 2017).
45. Leaf, W.A.; Simons-Morton, B.G.; Hartos, J.L.; Northrup, V.S. Driving miles estimates by teen drivers: How accurate are they? *Inj. Prev.* **2008**, *14*, 59–61. [[CrossRef](#)] [[PubMed](#)]
46. Ferguson, S.A.; Teoh, E.R.; McCartt, A.T. Progress in teenage crash risk during the last decade. *J. Saf. Res.* **2007**, *38*, 137–145. [[CrossRef](#)] [[PubMed](#)]
47. Klauer, S.G.; Simons-Morton, B.G.; Lee, S.E.; Ouimet, M.C.; Howard, E.H.; Dingus, T.A. Novice drivers' exposure to known risk factors during the first 18 months of licensure: The effect of vehicle ownership. *Traffic Inj. Prev.* **2011**, *12*, 159–168. [[CrossRef](#)] [[PubMed](#)]
48. Simons-Morton, B.G.; Ouimet, M.C.; Wang, J.; Chen, R.; Klauer, S.G.; Lee, S.E.; Dingus, T. Peer influence predicts speeding prevalence among teenage drivers. *J. Saf. Res.* **2012**, *43*, 397–403. [[CrossRef](#)] [[PubMed](#)]
49. National Highway Traffic Safety Administration. Distracted Driving 2015. DOT HS 812 381. Available online: <https://www.nhtsa.gov/document/traffic-safety-facts-distracted-driving-2015> (accessed on 17 May 2017).
50. National Highway Traffic Safety Administration. Driver Electronic Device Use in 2015. DOT HS 812 326. Available online: [https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/driver\\_electronic\\_device\\_use\\_in\\_2015\\_0.pdf](https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/driver_electronic_device_use_in_2015_0.pdf) (accessed on 17 May 2017).
51. Bingham, C.R.; Zakrajsek, J.S.; Almani, F.; Shope, J.T.; Sayer, T.B. Do as I say, not as I do: Distracted driving behavior of teens and their parents. *J. Saf. Res.* **2015**, *55*, 21–29. [[CrossRef](#)] [[PubMed](#)]
52. Klauer, S.G.; Ehsani, J.P.; McGehee, D.V.; Manser, M. The effect of secondary task engagement on adolescents' driving performance and crash risk. *J. Adolesc. Health* **2015**, *57*, S36–S43. [[CrossRef](#)] [[PubMed](#)]
53. Owens, J.M.; Angell, L.; Hankey, J.M.; Foley, J.; Ebe, K. Creation of the Naturalistic Engagement in Secondary Tasks (NEST) distracted driving dataset. *J. Saf. Res.* **2015**, *54*, 33–36. [[CrossRef](#)] [[PubMed](#)]
54. Gershon, P.; Zhu, C.; Klauer, S.; Dingus, T.; Simons-Morton, B. Teens' distracted driving behavior: Prevalence and predictors. *J. Saf. Res.* **2017**, *63*, 157–161. [[CrossRef](#)] [[PubMed](#)]
55. Simons-Morton, B.G.; Guo, F.; Klauer, S.G.; Ehsani, J.P.; Pradhan, A.K. Keep your eyes on the road: Young driver crash risk increases according to duration of distraction. *J. Adolesc. Health* **2014**, *54*, S61–S67. [[CrossRef](#)] [[PubMed](#)]
56. Simons-Morton, B.; Li, K.; Ehsani, J.; Vaca, F.E. Covariability in three dimensions of teenage driving risky behavior: Impaired driving, risky and unsafe driving behavior, and secondary task engagement. *Traffic Inj. Prev.* **2016**, *17*, 441–446. [[CrossRef](#)] [[PubMed](#)]
57. Klauer, S.G.; Sayer, T.; Ankem, G.; Baynes, P. Using real-time and post hoc feedback to improve driving safety for novice drivers. In Proceedings of the Human Factors and Ergonomics Society 60th Annual Meeting, Washington, DC, USA, 19–23 September 2016.
58. O'Brien, F.; Bible, J.; Liu, D.; Simons-Morton, B.G. Do young drivers become safer after being involved in a collision? *Psychol. Sci.* **2017**, *28*, 407–413. [[CrossRef](#)] [[PubMed](#)]
59. Ehsani, J.P.; Haynie, D.; Ouimet, M.C.; Zhu, C.; Guillaume, C.; Klauer, S.G.; Dingus, T.; Simons-Morton, B.G. Teen drivers' awareness of vehicle instrumentation in naturalistic research. *J. Saf. Res.* **2017**, *63*, 127–134. [[CrossRef](#)] [[PubMed](#)]

