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Novice Drivers' Exposure to Known Risk Factors During the First 18 Months of Licensure: The Effect of Vehicle Ownership

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Abstract

Objective—Though there is ample research indicating that nighttime, teen passengers, and speeding increase the risk of crash involvement, there is little research about teen drivers' exposure to these known risk factors. Three research questions were assessed in this article: (1) Does exposure to known risk factors change over time? (2) Do teenage drivers experience higher rates of exposure to known risk factors than adult drivers? (3) Do teenage drivers who own a vehicle experience higher rates of exposure to risk factors than those who share a family vehicle?

Methods—Forty-one newly licensed teenage drivers and at least one parent (adult) were recruited at licensure. Driving data were recorded for 18 months.

Results—Average vehicle miles traveled (VMT) or average nighttime VMT for teens did not increase over time. Teenagers consistently drove 24 percent of VMT at night, compared with 18 percent for adults. Teenagers drove 62 percent of VMT with no passengers, 29 percent of VMT with one passenger, and less than 10 percent of VMT with multiple passengers. Driving with no passengers increased with driving experience for these teens. Teenage drivers who owned their vehicles, relative to those who shared a vehicle, sped 4 times more frequently overall and more frequently at night and with multiple teen passengers.

Conclusion—These findings are among the first objective data documenting the nature of teenage driving exposure to known risk factors. The findings provide evidence that vehicle access is related to risk and suggest the potential safety benefit of parental management of novice teenage driving exposure.

Keywords

Teenage drivers; Risk factors; Exposure; Nighttime driving; Speeding; Teenage passengers

Introduction

Teenage drivers crash at disproportionately higher rates than do older drivers (Insurance Institute for Highway Safety [IIHS] 2005; Williams 2003). The factors associated with these high crash risks among novice teenage drivers include young age, inexperience, nighttime driving, teenage passengers, and speed (Williams 2003). The first year of driving is of particular interest because both parents and licensing policy seek to limit exposure to high-risk driving conditions among novices. However, there is little objective data about exposure to these risks among novice teenage drivers and how these exposures vary during the first year of licensure.

Drivers are at the greatest risk for crashes when first licensed (Mayhew et al. 2003; McCartt et al. 2003; Twisk and Stacey 2007). Though this risk declines rapidly during the first year of licensure, it remains elevated for young drivers until their mid-20s (Williams 2003). The pattern (highly elevated crash risk at licensure followed by a rapid decline for some months and then a more gradual decline) occurs regardless of the age of licensure, although this pattern of risk is attenuated by older age at licensure (Twisk and Stacey 2007). This pattern of risk is consistent with the vast literature about the development of complex psycho-motor skills showing that the learning process is prolonged and that experience is a necessary factor in learning. Indeed, substantial evidence has shown that novices are poor drivers. Olsen et al. (2006) found that novice teenage drivers, even after 6 months of driving, were less able than experienced adults to manage signalized intersections when engaging in a secondary task. Other research has shown that teenage drivers detect roadway hazards less efficiently than adult drivers (Deery 1999; Pollatsek et al. 2006).

The principles of graduated driver's licensing (GDL) and parental management of novice teenage drivers are practiced in several countries, including Australia, Europe, Canada, and the United States (McCartt et al. 2009). These principles allow novices to drive only under less risky driving conditions while they develop the skill and judgment necessary for safe driving. The more one drives, the greater the risk of a crash, but some types of driving are more dangerous than others.

Crash risk is greater at nighttime compared to daytime for drivers of all ages, but this risk is greater among younger than older drivers (Rice et al. 2003; Williams 2003). Teenagers are also more likely to self-report dangerous driving incidents (for which they would have been stopped if observed by police) at nighttime compared to during the day (Williams 2003). Logically, it has been recommended that novices should first gain experience driving during the day before driving at night. However, little is known about the relative exposure to nighttime and daytime conditions for teenage drivers.

It has also been shown that crash risk is greater in the presence of teenage passengers; 16-year-old drivers are 4 times more likely than experienced drivers to be carrying 2 or more passengers when involved in a fatal crash (Chen et al. 2006; Gonzales et al. 2005). Unfortunately, little information is available about how frequently novice teenagers drive with teenage passengers and how this exposure varies over time.

High-speed driving frequently contributes to fatal crashes among drivers at every age, but speed appears to be an especially important risk factor for young drivers (Williams 2003). Teenage drivers are twice as likely to have been speeding when involved in fatal crashes compared to experienced drivers (Gonzales et al. 2005). Other research has shown that teenagers, particularly males, drive somewhat faster than normal traffic, especially in the presence of male teenage passengers (Simons-Morton et al. 2005). However, there are no data about the prevalence of speeding among novice teenage drivers. Moreover, it would be of interest to determine the extent to which speeding varies over time, at night, and with teenage passengers.

Most of the available data about driving exposure are based on self-reported mileage from surveys such as the Nationwide Personal Transportation Survey (NPTS; Inter-University Consortium for Political and Social Research 2010). Although self-reported mileage cannot be accepted as fully reliable (eg, Leaf et al. 2007), McCartt et al. (2003) reported in one exposure study of 911 teenage drivers that mean mileage increased steadily from the first month of licensure to the 11th or 12th month and then stabilized, with average yearly vehicle miles traveled (VMT) of 4905. The 2001 National Household Travel Survey (NHTS; US Department of Transportation, Federal Highway Administration) reported an average estimate of 4380 miles driven per year for teen drivers compared to an estimated 12 775 miles driven by adults (aged 25–60 years).

Fortunately, recent advances in technology have made it possible to collect continuous distance and duration information for specific drivers. A variety of electronic recording devices are now available that can provide information about exposure, including total miles traveled. However, only devices with images or video can confirm driver identification, passenger characteristics, and speeding behavior. In a recent instrumented vehicle study, Farmer et al. (2009) recruited 85 newly licensed drivers (all aged 16 or 17), equipped their vehicles with an event-based monitoring system, randomized them to 4 feedback groups, and collected data for 20 weeks on mileage, safety belt use, and speeding. The system identified the driver who used a specially designed key fob; however, the lack of video meant that driver identification or passenger characteristic information could not be independently confirmed and that no information could be collected on passengers. In another instrumented vehicle study, Prato et al. (2010) examined 62 families with novice teenage drivers during the licensing process (both supervised and independent driving). In the independent driving phase of this study, males drove an average of 19.4 h per month and females drove 14.7 h per month. Notably, males also drove significantly more during the nighttime hours (10 pm to 6 am), with 34 percent of total driving hours occurring at night as opposed to 26 percent of female's driving hours at night. Thus, instrumented vehicles can provide detailed information regarding teen drivers' exposure to known risk factors; however, neither of these studies contained video to confirm driver identification or passenger information.

Several analyses have also shown that teenage VMT is different between those teenagers who own a vehicle (primary vehicle driver) and those teenagers who share a family vehicle (shared vehicle driver). Cammisa et al. (1999) conducted a survey of teenage drivers in 4 states in the northeastern United States and found that those teens who own a vehicle drove

more miles, raced more frequently, sped over 90 mph more frequently, and had a higher crash rate than did those teenagers who shared a family vehicle. Williams et al. (2006) conducted telephone interviews with 3,500 Connecticut teenagers and their parents and also found that teenagers who own their vehicles had significantly higher numbers of reported crashes and traffic violations as well as higher proportions of trips with risky behaviors. Garcia-Espana et al. (2009) also conducted a survey where they found that those drivers who own a vehicle had a crash risk 2 times higher and higher rates of speeding greater than 10 mph than those teen drivers who shared a family vehicle. Thus, there is evidence that teens with greater access to a vehicle during the early months of licensure may be at an increased risk of crashes.

Ultimately, though a great deal is known about teenage driving risks, there remains a lack of information about teenage drivers' exposure to known risk factors, especially during the first year to 18 months of licensure. Data about exposure can provide a more detailed understanding of which of these known risk factors may be more dangerous or result in higher crash and injury rates. The Naturalistic Teenage Driving Study (NTDS) (Dingus et al. 2006) provides a unique opportunity to assess such driving exposure to these known risk factors.

The purpose of this article is to report the findings about exposure from the NTDS to better assess the following research questions:

1. Does exposure to known risk factors change across the first 18 months of driving?
2. Do teenage drivers experience higher rates of exposure to known risk factors compared to adult drivers?
3. Do teenage drivers who own a vehicle experience higher rates of exposure to risk factors than those who share a family vehicle?

Methods

A highly capable data acquisition system was installed within 2 weeks of provisional licensure in the personal vehicles of teenage participants. In the state of Virginia, graduated driver's licensing laws require that novice drivers may obtain a learner's permit at the age of 15.5 years and must hold this permit for a minimum of 9 months. During this time, they are required to obtain 45 h of supervised practice driving and complete classroom driver's education instruction and behind-the-wheel instruction. Thus, the earliest that teenagers may receive their provisional license is at 16.25 years of age. For the first year of holding a provisional license, novice drivers must wear their seat belts, are not allowed more than one unrelated teenage passenger, and may not drive between the hours of 12:00 am and 4:00 am. Virginia drivers under the age of 18 are also not allowed to use a wireless device while driving.

Data were collected continuously for a period of 18 months. Interested readers should refer to Lee et al. (in press) for a complete description of the research methods.

Participants

A volunteer sample of forty-one 16-year-old teenagers (20 males, 21 females) and at least one parent (13 males, 29 females) for each teenage driver were recruited through advertisements and driving schools to participate in this naturalistic driving study. Recruitment for these 41 vehicles occurred between the months of June 2007 and March 2008; thus, seasonal affect by month of driving was highly variable given that some driver's first few months were summer/fall and some drivers first few driving months were winter/spring.

At the beginning of the study, 20 of the teenage participants were the primary driver of a vehicle, and 21 of the teenagers shared a family vehicle. Given the nature of unobtrusive field studies, the primary driver/shared driver classification became less distinct for several of the vehicles across the 18-month data collection period because some of the shared vehicle teenagers were driving the vehicle more trips/miles than their parents. Thus, an operational definition was employed whereby if a parent drove the instrumented vehicle for a minimum of 500 miles, the teenage driver was operationally defined as a shared vehicle driver. All other teenagers were labeled the primary driver. This operational definition designated 22 teenagers as shared vehicle drivers and 19 teenagers as primary vehicle drivers. Participants were from areas of southwestern Virginia, with most participants living in urban or suburban areas and a few living in rural areas (as defined by the United States Census). Participants received compensation for participation in various aspects of the study.

Consent—The protocol was reviewed and approved by the Virginia Tech Institutional Review Board. Parental consent for their own and their teenager's participation and each teenager's assent for participation were obtained. A Certificate of Confidentiality was obtained from the US Department of Health and Human Services to further protect the participants' privacy and identifiable information.

Vehicles—The data acquisition system was installed in participants' own vehicles. Seventeen vehicle makes were included in the study, covering 33 models (30 sedans, 5 minivans, and 7 sport utility vehicles), with model years ranging from 1991 to 2006.

Instrumentation—The data acquisition system, designed and developed by staff at the Virginia Tech Transportation Institute, consisted of a computer (LINUX-based PC) that received and stored data from a network of sensors in the vehicle. Sensors included Global Positioning Systems (GPS), accelerometers, video, and radar. Video of the vehicle cabin was examined for each trip to identify the driver, ambient lighting, and passenger presence. Mileage was obtained from a transmission sensor. Data from selected road segments were evaluated to assess speed in relation to known speed limits.

Dependent variables—The dependent measures that were used in the following analyses are described below:

- **Miles driven**—Calculated using a transmission sensor that measures the number of revolutions of the axle per mile traveled. This sensor was calibrated at the time of the data acquisition system installation.

- Night versus day—The percentage of miles traveled at night-time versus daytime was assessed by trained coders reviewing video and recording per trip whether the ambient lighting was daytime or nighttime. Periods of dawn or dusk were grouped with daytime. Using this coding, nighttime mileage was calculated for all of the trips that each driver traveled during darkness and was summed and divided by the total number of miles recorded for that driver.
- One analysis evaluated late night driving, which was operationally defined as driving between the hours of 12 am and 4 am, per Virginia GDL laws. Any calculation using late night driving was identified via initial timestamp per trip as time and date were recorded for each trip. The miles associated with these late night trips were then removed from the mileage calculated for nighttime (as defined by darkness) to create mutually exclusive mileage time periods.
- Passenger presence—The percentage of miles traveled per passenger condition was also assessed by trained coders reviewing video and recording both the presence of passenger(s) and age of passenger(s). Passenger age was assessed by trained coders reviewing the interior cabin and rear seat snapshots for each trip. For this analysis, only 2 ages of passengers were used. These ages and operational definitions are as follows
- Adult drivers were operationally defined as 19 years of age and older.
- Teenagers were aged 14 through 18. Using this coding, mileage for all of the trips per driver at each level of passenger presence was summed and divided by the total mileage for that driver. There were miles driven with passengers under the age of 14; however, this was less than 3 percent of total miles traveled. Though the Virginia GDL does not restrict teenage siblings, the following analyses were unable to differentiate between teenage siblings and friends. Thus, the percentages of trips reported with multiple teenage passengers are only possible GDL violations.
- Speeding—A sample of road segments was a priori identified as being frequently traveled, relatively straight in alignment, and containing no major intersections. The speed limit for each of these segments was also determined through field observations. On these road segments, the maximum speed exceeded for one tenth of a second was recorded and the posted speed limit subtracted. The frequency of speeding was calculated by dividing the total number of road segments with speeds greater than 5 and 10 mph over the speed limit by the total number of road segments.

Data coding inter- and intrarater reliability—Training procedures were implemented to ensure both inter- and intrarater reliability, given that data coders were asked to perform subjective judgments of the video and driving data, including number of passengers, ambient lighting, age of passengers (in categories), and gender of passengers. All data coded regarding passengers were based on blurred snapshots to protect the passengers' privacy. An expert coder rated the categories for each event used in the reliability tests, and coders were compared both to the expert and to one another. Numerous measures were tested during the interrater reliability tests, and the 2 with the greatest interest for future analyses were chosen

for statistical testing (the age categorization [adult or teen] and gender of the front seat passenger). The Fleiss kappa was chosen as the most appropriate method to test interrater reliability, given the large number of raters for each case in the test (there were 10–13 raters for each of the 80 cases tested). Three categories were used in each test: teenager, adult, and all other answers for passenger age category and male, female, and all other answers for passenger gender. The calculated Fleiss free-marginal kappa was 0.82 for age category and 0.83 for gender, both of which are interpreted by Landis and Koch (1977) as an almost perfect agreement.

Analyses

All statistical analyses were conducted using PROC GLM in the SAS statistical software package (SAS Institute Inc., Cary, NC). In all analyses, error terms were specified, and the results generated for type 3 mean squares (repeated measures) are reported.

For the analyses assessing changes during 18 months, the 18 months were collapsed into six 3-month segments of time (eg, months 1–3, months 4–6, etc.) or quarters. Collapsing into six 3-month quarters reduced the high degree of variability in the data and provided a better assessment of the trends existing in these data.

Novice driving data were compared to adult driving data for several of the research questions. Given that some teens shared a family vehicle versus other teens being the primary driver of a vehicle, sufficient driving data (500 miles) were only collected for 22 of the adult (ie, parent) drivers. These 22 parents were nearly all obtained from the participants who shared a family vehicle (18 parents) with the addition of 4 parents who indicated at the beginning of the study that their teenager would have the primary use of a vehicle. The variance associated with the 22 teens' parents used as the comparison group was accounted for in the statistical model using the between-subjects variable vehicle ownership. Paired teen–parent comparisons were also conducted with similar results; thus, the analyses using all the participants are reported.

The analyses present total VMT at 12 and 18 months and 18 months of data for 3 known risk factors: nighttime driving, presence of multiple teen passengers, and speeding, as well as the combinations of these risk factors. Exposure is measured in terms of mean mileage, percentage of total miles traveled, or percentage of road segments, depending on the risk factor and type of analysis. When percentages were used as the dependent variable, the rank transformation approach was used so that parametric analyses could be conducted (Conover and Iman 1981).

Results

Six participants had at least one month in which there were no miles collected from their instrumented vehicles (a total of 8 months across the 6 participants). The reasons for this data loss included extended family vacations, mechanical problems with the vehicle, disciplinary actions, and instrumentation failures. Though 42 teenage participants were recruited, one participant (primary driver) dropped out of the study at month 8 and is not

included in these analyses. Thus, 41 teenage drivers (22 shared and 19 primary vehicle drivers) and 22 adult drivers were included in the following analyses.

Variability in Mileage and High-Risk Driving Conditions

Total vehicle miles traveled—Figure 1 shows the total VMT by each teenage driver for 18 months. Twelve-month mileage is also shown for the sake of comparison to other studies reporting annual mileage (eg, McCartt et al. 2003). The range between the highest and lowest mileage drivers at 12 months was $\pm 3,582.5$ VMT with a mean of 4,120 VMT. The range in mileage at 18 months was $\pm 6,222.5$ VMT with a mean of 6,384 VMT.

Figure 2 shows the group mean and standard deviation in mileage across the first 18 months of driving in 3-month quarters. These results suggest an upward trend over time; however, the 2 (two types of vehicle ownership) $\times$ 6 (six 3-month quarters) repeated measures analysis of variance (ANOVA) was not statistically significant. Adults were not included in this comparison; adults also drove other vehicles, so an accurate estimate of total VMT was not available for adult participants.

A separate analysis of calendar month was conducted to ensure that the calendar month (eg, seasonal effects) was not a confounding factor when assessing VMT across months of driving. The repeated measures ANOVA also indicated no significant differences for mileage across calendar months.

Nighttime driving—Figure 3 shows the mileage percentage for teenagers and parents driving during daytime, nighttime, and late night as defined by GDL curfew hours of 12 am to 4 am. Teenagers drove a higher percentage of miles at night compared to adults. Both teenagers and parents drove approximately 1 percent of their miles during late night hours, although parents may have driven other vehicles late at night. Using the ranked transformation approach, a $2 \times 2 \times 6$ ANOVA was conducted to assess differences between exposure to nighttime driving by driver type (parents versus teenage driver), vehicle ownership (primary driver versus shared vehicle driver), and time (six 3-month quarters). The results indicated that the teenagers drove a significantly higher percentage of total miles at night compared to the adults, $F(1, 61) = 12.8, p < .05$. There was not a statistically significant effect for month, vehicle ownership, or any of the interactions.

Driving with passengers—For the first 18 months, teenagers drove an average of 62 percent of their total mileage without any passengers, 29 percent of their mileage with one passenger, and only 8 percent of their mileage with 2 or more passengers (remainder is unknown). Of the miles driven with at least one passenger, 68 percent of VMT was with a teenager, 17 percent with an adult, and 9 percent with a child under the age of 13. Figure 4 shows the percentage miles traveled by teenagers with at least one passenger. A $2 \times 3 \times 6$ repeated measures ANOVA was conducted with vehicle ownership (primary driver or shared vehicle driver), passenger type (no passenger, teen passenger, or adult passenger), and month group (six 3-month quarters). The results indicated a significant interaction of month group by passenger type, $F(10, 400) = 4.52, p < .05$. A Tukey' post hoc honestly significant difference (HSD) test indicated that adult passengers decreased significantly from the first quarter compared to the sixth quarter, $HSD(1) = 4.0, p < .05$. A significant

effect was also found for passenger type by vehicle ownership, $F(2, 78) = 5.0, p < .05$. The Tukey's post hoc test indicated a marginally statistically significant finding indicating that teenage drivers who shared a vehicle (mean = 14.3%) drove with an adult more frequently than those teenaged drivers who were the primary vehicle driver (mean = 3.1%), $HSD(1) = 2.7, p = .09$.

An additional analysis was conducted to assess the percentage of miles driven by passenger presence for teenage and adult drivers, aggregated across 6 quarters. The results indicated that teenagers drove increasingly more miles with no passengers over time, from just over 50 percent during the first quarter to about 65 percent during the last quarter. Concomitantly, average miles with one passenger declined over time. Meanwhile, there was no apparent change in passengers among adult drivers.

The previous results included passengers of any age; however, because the presence of teenage passengers specifically has been shown to be a risk factor for teenage drivers, Figure 5 shows the mean mileage percentage for teenage drivers across months of driving with no passengers, one teen passenger, and multiple teen passengers. A repeated measures $3 \times 2 \times 6$ ANOVA was conducted on 3 passenger groups (0, 1, or 2+ passengers), 2 levels of vehicle ownership, and six 3-month quarters. The interaction of quarters and number of teenage passengers was significant, $F(10, 399) = 3.1, p < .05$. Tukey's post hoc tests indicated that teenage drivers drove increasingly more miles alone across months of driving. This result was true when comparing quarters 1 and 5, $HSD(1) = 4.0, p < .05$, and quarters 1 and 6, $HSD(1) = 4.5, p < .05$. Similar numbers of miles were traveled with one teen passenger or multiple teen passengers across 18 months of driving.

Speeding

Figure 6 shows the percentage of road segments where adult and teenage drivers exceeded the speed limit by 10 mph for 0.1s, aggregated across quarters. Note that the percentage of speeding was higher among adults during the first 6 months but higher among teenagers than adults thereafter. A 3-way $2 \times 2 \times 6$ repeated measures ANOVA was conducted for driver type (parent or teen), vehicle ownership (primary driver versus shared vehicle), and quarter (six 3-month segments). The results showed that the interaction of quarter and driver type was significant, indicating that teenage drivers increase their engagement in speeding greater than 10 mph over time relative to adults, $F(5, 291) = 4.4, p < .05$. The main effect of vehicle ownership was also significant, indicating that teenage drivers who have primary ownership of a vehicle (mean = 18.5%) speed 2 times more frequently than do those teenagers and adults who share a vehicle (mean = 9.7%). An analysis was also conducted for the percentage of speeding between 5 and 9.9 mph over the speed limit, which indicated no significant differences across a 3-month period of driving or between teenage drivers and adult drivers.

To further assess the effects of vehicle ownership for teenage drivers only, a second 2×6 repeated measures ANOVA was conducted for vehicle ownership (primary driver versus shared vehicle driver) and quarter (six 3-month segments). This analysis indicated significant main effects for both vehicle ownership and quarter but not a significant interaction of the 2 variables (Figure 7). Teenage drivers who were the primary driver of a

vehicle were observed speeding greater than 10 mph more frequently (mean = 18.5%) than teenagers who shared a vehicle (mean = 8.9%), $F(1, 38) = 7.6, p < .05$. Speeding also increased across months of driving for teenage drivers, $F(5, 189) = 2.5, p < .05$.

Interaction of risk factors—nighttime driving and speeding—An analysis was conducted for nighttime driving and speeding greater than 10 mph. Late night speeding was not evaluated separately due to the low mileage among both teens and adults for this condition. Speeding frequency at night was relatively low across the 18-month period, about 3.0 percent for teens and 0.8 percent for adults. Evaluating only teenage speeding at night, a 2-way 2×6 repeated measures ANOVA was conducted where vehicle ownership (primary driver versus shared vehicle driver) and quarter (six 3-month groups) indicated a significant interaction of quarter by vehicle ownership (Figure 8). A Tukey's post hoc HSD test indicated that teenagers with primary ownership sped at night significantly more frequently during the last quarter compared to the second quarter, $HSD(1) = 3.9, p < .05$, or third quarter, $HSD(1) = 3.6, p > .05$. The main effect of vehicle ownership was also significant, indicating that teenage drivers who are the primary driver (mean = 4.4%) of a vehicle sped more frequently at night than did the drivers who shared a vehicle (mean = 1.3%), $F(1, 39) = 5.3, p < .05$.

Interaction of speeding and teen passenger presence—Shown in Figure 9 are the frequencies of teenage speeding greater than 10 mph with one or more teenage passengers. A repeated measures ANOVA was conducted on 2 levels of vehicle ownership and six 3-month quarters. The interaction of vehicle ownership and quarters was significant, $F(5, 190) = 3.1, p < .05$. Teen drivers who are the primary driver of a vehicle were found to speed increasingly more frequently with teen passengers over time than those teenagers who share a vehicle. A Tukey's post hoc test between the first and sixth quarters for primary teenage drivers indicated a significant increase in speeding frequency, $HSD(1) = 3.9, p > .05$.

Discussion

Precise exposure data for novice teen drivers have previously been unavailable. The NTDS provides the first objective data about exposure of novice teen drivers under well-known, high-risk conditions. The following discussion focuses on the 3 research questions proposed in the Introduction.

1. Does exposure to known risk factors change across the first 18 months of driving?

Though the total VMT per teenage driver was highly variable, there was not a significant increase in mileage across 18 months. The high variability in mileage could be due to natural variations due to teen activities, schedules, and need to drive; vehicle access; available transportation options; and parental supervision. The lack of an increase in mileage over time is inconsistent with McCartt et al. (2003), who found a significant increase in mileage across the first 12 months of independent driving. Though the McCartt et al. (2003) sample was larger than the sample presented here, their results relied on self-report. Thus, the increase in mileage in the McCartt et al. (2003) data may have been due to teenagers improving their estimations of VMT. Alternatively, differences in the 2 studies may be due

to variations in the regions or study participants. The finding that mileage did not increase in our sample suggests that there was no period of reduced exposure during the early and dangerous first months of independent driving. Similarly, in our sample, there was no increase over time in the percentage of miles teenagers drove at night, suggesting inadequate limits for nighttime driving during the first months of licensure as recommended.

Teenagers drove alone most of the time, and this percentage increased over time. Though the crash risk imposed by one teenage passenger is much less than the risk imposed by multiple teenage passengers (Ouimet et al. 2010), a strong case can be made for limiting novice teenage drivers to no teenage passengers for a period of time as they gain essential driving experience, both to reduce driver distraction and to protect passengers during the highest risk driving period.

Virginia GDL laws limit novices to one teenage passenger for the first 12 months of licensure. However, siblings are exempt. Our data showed that teenage drivers drove with multiple teen passengers about 10 percent of VMT throughout the 18 months. However, it was not possible for coders to distinguish between friends and siblings, so it is not clear the extent to which teenage drivers violated the state GDL law.

Related to this is the relatively low rate and the significant decrease over time of teenagers driving with adult passengers during the first 18 months of driving, less than 15 percent of miles driven in the first quarter and less than 10 percent thereafter. Of course, teenagers may have driven with their parents in other vehicles. It is well documented that parental supervision is a critical component in improving driver safety for teen drivers (Simons-Morton et al. 2008). The decrease in adult supervision of teen drivers over time is concerning because other analyses have demonstrated an increase in risky driving behavior such as speeding over the same time period.

A significant upward trend for speeding greater than 10 mph was observed across 18 months of driving, indicating that these teenage drivers engaged in speeding more frequently over time. Though this finding could be a direct result from the decreased parental supervision over time, it could also result from increased teen driver confidence, increased number of purposeful trips where a timely arrival is necessary, decreased belief that speeding behavior will result in a traffic violation, or a combination of these reasons. Further research would be necessary to more fully understand this increase in speeding behavior over time.

2. Do teenage drivers experience higher rates of exposure to known risk factors compared to adult drivers?

Twenty-three percent of teenagers VMT occurred during nighttime driving, whereas adults only drove 18 percent of their mileage at night. One possible explanation for the significant increase in the percentage of nighttime driving by teens (as compared to parents) may be that many teenage drivers shared a vehicle with their families. These drivers may have access to vehicles shared with a parent only at night when their parents are not using the vehicle to commute to work or run errands. Alternatively, adults may have been likely to drive at night in vehicles not instrumented for the study, which would provide an underestimate of nighttime driving among adults. Further analyses with data collected in

varying geographic regions of the United States may also find different results given that amount of sunlight varies not only by calendar month but also by geographic region.

Though both teenagers and adults drove greater than 10 mph over the speed limit (13.5% of road segments for teenagers and 11.8% for adults), speeding among teenagers significantly increased over time, suggesting more of an increase in exposure to risk than a decrease due to greater experience and improvements in driving skill and judgment.

3. Do teenage drivers who own a vehicle experience higher rates of exposure to risk factors than those who share a family vehicle?

Though vehicle ownership was not associated with exposure to nighttime driving or teen passenger presence, it was associated with speeding and potentially associated with amount of adult supervision. Relative to teenagers who shared a vehicle, teenagers who were the primary driver of the vehicle sped 4 times more frequently overall and significantly more often at night and more often with teen passengers. This pattern of behavior actually got worse rather than better over time. The marginally significant result of percent VMT with an adult present further suggests that more adult supervision may reduce the prevalence of risky driving behaviors in teenage drivers.

These results are consistent with previous research that reported higher crash rates for teenagers who own a vehicle versus those who share a vehicle (Cammisa et al. 1999; Williams et al. 2006). It cannot be determined whether teenagers with their own vehicles drive in a more risky manner because they have exclusive access to a vehicle or whether teenagers who tend toward risk taking are better able to gain exclusive access to a vehicle than adolescents who are less risk taking. Further research is necessary to better understand the fundamental differences between teenagers who own a vehicle and those who share a vehicle.

Assuming that the findings are not simply a matter of selection, it is of interest to determine whether there is something about exclusive access to a vehicle that contributes to speeding among teenagers. Could exclusive access to a vehicle contribute to teenagers' sense of independence and/or invulnerability or simply provide them with greater opportunity? Conversely, it could be that sharing a vehicle with a parent exerts a conservative influence on teenage drivers, making teenagers less likely to take risks with the vehicle because it is not really theirs, they perceive that their parents would not approve, or possibly that parents would find out about their risky driving behavior. The primary implication of these findings is that it may be possible for parents to limit teenage driving risks by sharing a vehicle with them, riding with them, and delaying the time when their teenager gains exclusive access to a vehicle.

Limitations

Though these data represent the first objective mileage data collected in the United States to date, the sample was regional and may not generalize to dense urban or purely rural areas. Further, the small sample size ($N = 41$) prevented more in-depth analyses of combined risk factors (eg, speeding with teenage passengers at night). The data are based on the

instrumentation installed in the primary vehicle driven by the teen; 21 teenagers were the primary drivers of the instrumented vehicle, and 18 of the teenagers shared an instrumented vehicle with other family members. Teens may have driven other vehicles that were not instrumented, and these miles were not assessed. Also, parents who shared an instrumented vehicle with their teen may also have driven other family vehicles, and the mileage collected for adults in our study was less than the national average. Comparisons between adult and teenage drivers did not take into account possible similarities between parents and their teenage children for the following reasons: only 22 parents had sufficient data to be included; parents were treated as an adult comparison group; and interfamilial correlations would not have confounded the analyses. All participants voluntarily agreed to participate in the study and have their vehicle instrumented with cameras and data collection equipment. Thus, there may be some latent bias in the sample toward acceptance of technology and/or video recording. It could not be determined whether the effect of exclusive access to a vehicle on speeding was due to those who gained such access compared to those who shared a vehicle or to the nature of sharing a vehicle with a parent.

Conclusions

Because crash risk is highest during the first 6 months of licensure, policy and practice recommendations favor limiting driving during this period to lower risk driving conditions, allowing teens to develop independent skills and the judgment needed to deal with more complex driving conditions (Ferguson et al. 2007). Though it is not possible in this study to evaluate the effect of policy limitations on exposure, the findings indicated that from the moment of licensure teenagers drove frequently, at night, and with passengers. Thus, teenagers in this study were exposed to known risk factors at high rates during the period of highest crash risk. Though the GDL laws in Virginia place restrictions on night driving and passenger presence, these laws could be improved to further reduce the risks to which teenaged drivers are exposed. Increasing the nighttime hours under restriction as well as not allowing any teen passenger for a period of time after licensure may yield further reductions in teenage crash rates. Meanwhile, parents drove infrequently with teenagers during this period, allowing them few opportunities to provide instruction and reinforce their expectations for safe driving behavior. The findings suggest that it may be possible for parents to reduce teenage driving risks by sharing a vehicle with them and delaying for a time when their teenager gains exclusive access to a vehicle.

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Figure 1.
Teenager cumulative VMT for 12 and 18 months of driving ($n = 41$).

Figure 2.
Teenage driver mileage across months of driving with standard deviation.

Figure 3.

Percentage total miles that teenagers and adults drove during observed daytime, observed nighttime, or late night (between the hours of 12 am and 4 am).

Figure 4.
Percentage VMT for teenage drivers with adult or teenage passengers.

Figure 5.

Teenage passengers: mileage percentage during the first 18 months of teenage driving with no passenger, 1 teen passenger, and 2 or more teen passengers. Note: percentages within groupings do not sum to 100 percent because adult and child passengers were not included in this analysis.

Figure 6.
Percentage of road segments where teens and adults exceeded 10 mph above the posted speed limit during months of driving.

Figure 7.
Percentage of road segments where teenage drivers were speeding greater than 10 mph.

Figure 8.
Percentage of road segments where teenage drivers were observed speeding (greater than 10 mph) at night.

Figure 9.
Percentage of road segments where teenagers were observed speeding above 10 mph with teenage passengers.