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Naturalistic assessment of novice teenage crash experience

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ABSTRACT

Background: Crash risk is highest during the first months after licensure. Current knowledge about teenagers' driving exposure and the factors increasing their crash risk is based on self-reported data and crash database analyses. While these research tools are useful, new developments in naturalistic technologies have allowed researchers to examine newly-licensed teenagers' exposure and crash risk factors in greater detail. The Naturalistic Teenage Driving Study (NTDS) described in this paper is the first study to follow a group of newly-licensed teenagers continuously for 18 months after licensure. The goals of this paper are to compare the crash and near-crash experience of drivers in the NTDS to national trends, to describe the methods and lessons learned in the NTDS, and to provide initial data on driving exposure for these drivers.
Methods: A data acquisition system was installed in the vehicles of 42 newly-licensed teenage drivers 16 years of age during their first 18 months of independent driving. It consisted of cameras, sensors (accelerometers, GPS, yaw, front radar, lane position, and various sensors obtained via the vehicle network), and a computer with removable hard drive. Data on the driving of participating parents was also collected when they drove the instrumented vehicle.
Findings: The primary findings after 18 months included the following: (1) crash and near-crash rates among teenage participants were significantly higher during the first six months of the study than the final 12 months, mirroring the national trends; (2) crash and near-crash rates were significantly higher for teenage than adult (parent) participants, also reflecting national trends; (3) teenaged driving exposure averaged between 507 and 710 km (315–441 miles) per month over the study period, but varied substantially between participants with standard errors representing 8–14 percent of the mean; and (4) crash and near-crash types were very similar for male and female teenage drivers.
Discussion: The findings are the first comparing crash and near-crash rates among novice teenage drivers with those of adults using the same vehicle over the same period of time. The finding of highly elevated crash rates of novice teenagers during the first six months of licensure are consistent with and confirm the archival crash data showing high crash risk for novice teenagers. The NTDS convenience sample of teenage drivers was similar to the US teenage driver population in terms of exposure and crash experience. The dataset is expected be a valuable resource for future in-depth analyses of crash risk, exposure to risky driving conditions, and comparisons of teenage and adult driving performance in various driving situations.

1. Introduction

The elevated crash risk for novice young drivers has been well documented. This heightened risk is present whether exposure is measured by distance driven, by trips taken, or by population. In the United States, Williams (2000) reported crash rates in 1995 at 34.5 per 1.6 million km (1 million miles) driven for 16 year olds, compared to 20.2 for 17 year olds, 13.8 for 18 year olds, and 3.9 for 30–69 year olds. This finding highlights both the elevated rate for novice drivers as compared to adults, and the rapid decline in crash rate over the first months of driving. Ferguson et al. (2007) found that in the seven years after 1995 (when graduated driver's licensing [GDL] laws were put into effect in most jurisdictions in the United States), the crash rate per million km (miles) driven had decreased for teenage drivers, but that crash risk was still much higher for teenage drivers than for older drivers. Possible reasons for this

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elevated crash risk include inexperience, immaturity, inadequate skill development, faulty decision making, and distraction. In addition, novice young drivers have increased crash risk in the presence of teen passengers (Chen et al., 2000; Ouimet et al., 2010) and at night (Williams, 2003). Moreover, there is a concern that secondary task engagement among novice young drivers may be highly prevalent and may increase crash risk (Klauer et al., 2006; Olsen et al., 2005). The primary source of teen crash data over the past few decades has been crash databases such as those maintained by the US National Center for Statistics and Analysis (NCSA, 2009). These databases rely on police accident reports and have provided the information containing the elements necessary for a successful graduated driver's licensing (GDL) program. However, they do not provide good information on what happens in the vehicle prior to a crash. New development in technologies allowing naturalistic studies (i.e., observation of behaviors without interference) can help increase our understanding of crash-related factors.

Continuous naturalistic data collection with the inclusion of video enables analysis of risks for a variety of outcomes (e.g., speeding, acceleration, and close following) and for a variety of behaviors and conditions (e.g., in the presence or absence of teen passengers; at night vs. during the day; while using secondary devices compared with not using them; when alert vs. fatigued). Early examples of this method included the Local Short Haul Study examining commercial drivers making day-long runs (Hanowski et al., 2000), the Sleeper Berth Study examining long-haul commercial truck drivers (Neale et al., 2002), and the Lane Change Study examining characteristics of lane changes in light vehicles (Lee et al., 2004). These efforts culminated in the 100-Car Study examining the driving behavior of 100 drivers over one year of continuous data collection (Dingus et al., 2006). To study crash-related factors in teenagers, researchers have also recently begun using either continuous sensor data with no video (e.g., Lotan and Toledo, 2005; Farmer et al., 2009), or triggered, episodic data which includes video (e.g., McGehee et al., 2007).

The current research builds on these earlier and ongoing efforts, by collecting continuous data with video in newly-licensed 16-year-old drivers. The Naturalistic Teenage Driving Study (NTDS) is thus believed to provide both the broadest and most detailed examination of teen driving behavior attempted to date. The purposes of this paper are to examine (1) the rates of crashes and near crashes among teen and adult participants; and (2) report trends for the crash and near crash rates over the 18 months of the study. In addition, the paper describes the methods and lessons learned in the NTDS, and also provides preliminary data on driving exposure and crash and near-crash experience.

2. Methods

In this study, the primary vehicles of newly-licensed teens were instrumented with a sophisticated set of vehicle monitoring devices within three weeks of licensure, and participants were instructed to drive as they would normally. Multiple measures were assessed over the first 18 months of licensure, including surveys (at baseline and 6-, 12-, and 18-months follow-ups), biological assessments (at baseline), and test track evaluations (at baseline and 12-month follow-up). This report focuses exclusively on the continuous instrumented vehicle data, which were recorded and stored and evaluated weeks or months after collection.

2.1. Participants and selection criteria

Recruitment of male and female newly-licensed drivers and one of their parents was conducted using newspaper advertisements, flyers, and driving schools from the New River Valley and Roanoke Valley areas of the Commonwealth of Virginia in the United States. Inclusion criteria, evaluated in a prescreening telephone interview, were: (a) being less than 17 years old (the youngest age in Virginia to obtain a provisional license is 16.25 years old); (b) holding a provisional driver's license allowing independent driving for no more than three weeks; (c) having at least one parent willing and able to participate; (d) having access to a vehicle expected to survive mechanically for at least 18 months; (e) living within a one hour drive of the research center; and (f) having liability insurance on the vehicle to be used in the study (as required by state law). The exclusion criteria were: (a) diagnosis of attention deficit disorder (ADD) or attention deficit hyperactivity disorder (ADHD) due to driving deficiencies demonstrated by these drivers (e.g., Barkley, 2004); (b) identical twins (difficult to distinguish when coding); (c) need to enter restricted areas (i.e., that do not allow cameras for security reasons); and (d) having only access to a pick-up truck (due to lack of a concealed space to install the instrumentation). Participants were stratified in order to have a similar number of males and females and of drivers sharing and not sharing a vehicle with their parents. Oversampling of females not sharing a vehicle with their parents was necessary at the end of the study to fill out all the cells.

2.2. Consent

The protocol was reviewed and approved by the Virginia Tech Institutional Review Board for the Protection of Human Subjects. There were three consent forms for the naturalistic portion of the study, including parent consent for their own participation, and parent consent and teen assent for teen participation. A Certificate of Confidentiality, which is required in the United States to protect participants' privacy and data from forced disclosure, was also obtained from the Department of Health and Human Services. Each teenager was informed about the study and asked to assent separately from their parent to ensure that participation was voluntary and free of parental coercion. Parents were told from the beginning that they would have no access to the video or other data from their teenage driver. Consent was also obtained to use naturalistic data from secondary parents (those who did not participate in the other parts of the study but who sometimes drove the vehicle).

Given the substantial commitment involved, participants were provided incentives of $75 for each month of participation in the naturalistic part of the study up to 18 months. For other parts of the study, including questionnaire and test track testing, participants were paid $20 per h. Upon completion of the study, participants received a bonus of $450 for completing all aspects of the study, for a total of approximately $2000 for the entire study. To put this payment in perspective, it is roughly the amount of money required to obtain vehicle insurance for a newly-licensed teen driver with good grades and a fairly new vehicle for 18 months. Payment was made through direct deposit into an account of the teen's choice.

2.3. Vehicles and instrumentation

Special brackets were designed that allowed the instrumentation to be installed in vehicles. The NTDS instrumentation package, designed and developed by staff at the Virginia Tech Transportation Institute (VTTI), consisted of a computer (LINUX-based PC) that received and stored data from a network of sensors in the vehicle. In addition to data collected directly from the vehicle network, sensors included: (1) four channels of continuous video to validate any sensor-based findings; (2) a video-based lane tracking system; (3) an accelerometer box that obtained longitudinal, lateral, and yaw kinematic information; (4) a radar-based headway detection system to provide information on leading vehicles; (5) a GPS to collect vehicle position information and to allow for geo-spatial

Fig. 1. (a) Quad-image of four continuous video feeds. (b) Quad image with two continuous video feeds (top) and two still frames (bottom).

analysis and sampling; and (6) an incident box to allow drivers to flag incidents.

As illustrated in Fig. 1a, the video subsystem included four continuous camera views monitoring the driver's face and driver side of the vehicle, the forward view, the rear view, and an over-the-shoulder view of the driver's hands and surrounding areas. Two other cameras provided periodic still shots of the interior vehicle cabin as well as the lap area of the rear passenger seat (Fig. 1b, bottom two frames). These two still shots allowed coders to assess the number of passengers in the vehicle, as well as the sex, age group, and seat belt use of all passengers, while still protecting their anonymity. There was no audio except for 30 s whenever the incident button was pressed (to allow the driver to describe what had just occurred).

2.4. Data coding

Data coding was conducted on each trip file and also on kinematically-triggered crashes and near-crashes.

2.4.1. Trip files

A trip was operationally defined as beginning when the vehicle ignition is turned on and ending when the ignition is turned off. Video footage of each trip taken by each instrumented vehicle was evaluated to determine the driver and passenger characteristics and other relevant information. Data coders recorded the participant identification number for the driver, the number of passengers, an estimate of the age category and sex of each passenger, and passenger seat belt use.

2.4.2. Crash and near-crashes

Trained data coders also reviewed the video and the corresponding driving performance data for excessive g-force events allowing the identification of crashes and near-crashes (collectively referred to as *events*). Potential events were identified in the data stream using kinematic data triggers as shown in Table 1 (these kinematic triggers identified behaviors such as fast stopping, rapid starting, rapidly approaching a lead vehicle, swerving, and self-reported events). Once a potential event was identified, data coders reviewed the corresponding video and classified the event as either a crash or as a near-crash as defined below:

Crash: Any contact with an object, either moving or fixed, at any speed in which kinetic energy is measurably transferred or dissipated. Includes other vehicles, roadside barriers, objects on or off of the roadway, pedestrians, cyclists, or animals. For this paper, crash rates were calculated by dividing the number of crashes and near-crashes for every three-month period by kilometers traveled over the same three-month periods.

Near-crash: Any circumstance that requires a rapid, evasive maneuver by the subject vehicle, or any other vehicle, pedestrian, cyclist, or animal to avoid a crash. A rapid, evasive maneuver is defined as steering, braking, accelerating, or any combination of control inputs that approaches the limits of vehicle capabilities as defined in Table 1.

It should be noted that including near-crashes has many advantages for event analyses. First, a near-crash is an event that itself should be avoided since, by definition, a successful, last-second evasive maneuver is required to avoid a crash. Second, near-crashes can provide unique insight into the elements and factors associated with successful crash avoidance maneuvers for comparison to unsuccessful (i.e., crash) circumstances. Third, near-crashes, since they (by definition) have many of the same characteristics as a crash, may provide useful insight into the crash risk associated with driver behavior and environmental factors. This third benefit can provide a powerful tool for analyzing naturalistic driving data since near-crashes occur at a rate of roughly 10–15 times higher than crashes. Finally, combining crashes and near-crashes provides a sufficient number of events for useful analyses.

2.5. Data coding inter- and intra-rater reliability

Training procedures were implemented to assure both inter- and intra-rater reliability, given that data coders were asked to perform subjective judgments on the video and driving data, including

Table 1
Values of the triggers used to identify potential crashes and near-crashes in the data.

Trigger name	Value
Longitudinal deceleration	≤ -0.65 g longitudinal deceleration
Lateral acceleration	± 0.75 g lateral acceleration
Forward time-to-collision	Forward time-to-collision of 4.0 s coupled with longitudinal deceleration of ≤ -0.6 g
	Forward time-to-collision of 4.0 s coupled with longitudinal deceleration of ≤ -0.5 g and less than 30.5 m (100 ft) to lead vehicle
Yaw rate	Vehicle swerves from $\pm 4°$/s to $\pm 4°$/s within a window of 3.0 s
Critical incident button	Boolean response (event was then examined to determine if it qualified as a crash or near crash)

Note. g = gravity; s = seconds.

Table 2
Teenagers and adults sociodemographic information ($N = 42$).

	Mean (SD) or [%]
Teenagers	
Age	
Male	16.4 (0.3)
Female	16.4 (0.2)
Race/ethnicity	
White	[92.9%]
Hispanic	[4.8%]
Asian	[2.4%]
Vehicle driven	
Sedan	[71.4%]
Minivan	[11.9%]
SUVs	[16.7%]
Adults	
Age	
Male	49.4 (5.3)
Female	45.7 (5.1)
Family income	
≥$100,000	[41.5%]
<$100,000	[58.5%]

number of passengers, ambient lighting, seat belt use of driver and passengers, age of passengers (in categories), and gender of passengers. The reader should keep in mind that all data coded regarding passengers was 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 inter-rater reliability tests, and the two with the greatest interest for future analyses were chosen for statistical testing (the age categorization [adult or teen] and sex of the front seat passenger). The Fleiss Kappa was chosen as the most appropriate method to test inter-rater reliability, given the large number of raters for each case in the test (there were from 10 to 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 sex. The calculated Fleiss free-marginal Kappa was 0.82 for age category and 0.83 for sex, both of which are interpreted by Landis and Koch (1977) as almost perfect agreement.

2.6. Data analysis

For this paper, crash and near-crash rates were calculated by combining and dividing the number of crashes and near-crashes for every time period of interest by kilometers traveled over the same time period. To examine if there was change in exposure over the first 18 months of independent driving, a regression analysis was performed. A general linear model was used to compare rates of crashes/near-crashes for the first six vs. the last 12 months and to compare the rates for adults vs. teens.

3. Findings

3.1. Participants and vehicles

Recruiting procedures yielded 315 teenager candidates. Of those, 117 (43 percent) had been licensed for too long; 44 (16 percent) did not fit into the remaining available slots in the research design; 30 (11 percent) had an ineligible vehicle type such as a pickup truck; and 82 (30 percent) were not included for other reasons, such as living too far away from the study site or being diagnosed with ADHD. A final sample of 42 newly-licensed teenagers (20 males and 22 females) and one of their parents (13 males and 29 females) was recruited. Teenage and adult participant socio-demographic information is shown in Table 2. Teenage participants were mostly Caucasians and drove a sedan. Seventeen vehicle makes were included in the study, covering 33 models. Model years ranged from 1991 to 2006; 76 percent of the vehicles were no more than 10 years old when data collection began. Also, thirty-nine of the participants were from nine different high schools, and three participants were home-schooled. Male adult participant were older than females ($t(41) = 2.02$, $p = 0.03$). Over half of the families had an income equal to or higher than $100,000 USD per year.

Table 3
Crash and near-crash frequency by age group and sex.

	Teens M	Teens F	Adults M	Adults F	Total
Crash	13	25	1	1	40
Near-crash	121	126	16	16	279

3.2. Database

Data collection started in June of 2006 and was completed in September of 2008. The overall data collected during the naturalistic phase includes video and kinematic data for nearly 102,000 trips taken by teen participants and their parents over approximately 800,000 km (500,000 miles). The data, including video and sensor data, consists of 5.1 terabytes. Although the amount of data collected was quite large, and much larger than any teenage driving data set collected to date, there were still issues of low exposure to certain driving situations, which will be discussed in the next section.

3.3. Exposure

Teenagers drove an average of 590 km per month during the study period, from 507 km (315 miles) in the first month to 710 km (441 miles) in the last month. There was a wide between-subjects range of exposure to driving, as shown by the standard error bars in Fig. 2 (for kilometers of driving per month). When analyzed on a monthly basis using regression analysis, the increase over time was not statistically significant.

3.4. Crashes and near-crashes

Teenage and adult crash and near-crash involvement by sex is shown in Table 3. The difference in crash involvement between males and female teenagers was primarily due to one female driver who was involved in 13 high speed curb strikes (at high speeds, a curb strike results in a high longitudinal deceleration spike, and can cause loss of control of the vehicle). Excluding this female driver, the numbers of crashes and near-crashes were nearly identical for male and female teenage drivers. Table 3 includes all 319 crashes and near crashes experienced by consented adult and teen drivers over the course of the study. Subsequent analyses presented in this paper take time in study (up to month 18) into account, and thus excluded six crashes and near crashes experienced by a teen who dropped out after month 8 and six crashes and near crashes that occurred in month 19.

Fig. 3 shows the rate of crash and near-crash involvement for teen and adult drivers per 16,000 km (10,000 miles) across the first 18 months of driving. Months 1–6 were combined and compared to months 7–18; crash and near-crash rates in these groupings varied significantly, with months 1–6 having a significantly higher overall combined crash and near-crash rate than months 7–18 ($F_{1,91} = 5.36$, $p = 0.0229$). Teen rates were significantly higher than parent rates ($F_{1,91} = 26.39$, $p < 0.0001$). For teens, male and female rates did not differ significantly ($F_{1,40} = .03$, $p = 0.6170$). The crash and near-crash rate by month grouping dataset contained data for 41 teens (exclud-

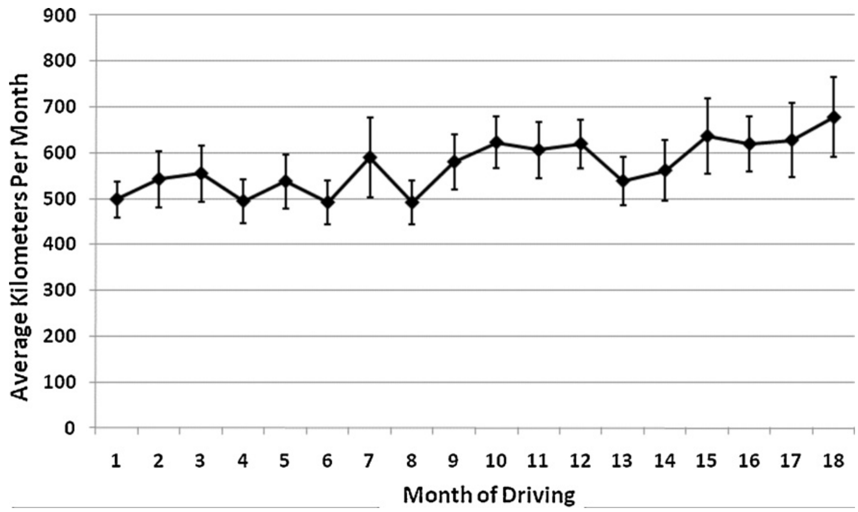

Fig. 2. Average number of kilometers driven by teenagers per month (with between-subject standard error bars).

ing one who dropped out after 8 months), 41 primary parents, and 13 secondary parents, and 307 crashes and near crashes. This paper provides only descriptive statistics regarding the age and experience of participants and their crash rates over time. This scope of this paper does not allow for modeling the data to account for the factors associated with those crashes. Such modeling would require sophisticated analytic techniques to account the non-normal distribution of crash and near crash rates (i.e., that many participants, especially adult participants, had no crashes or near crashes).

Table 4 provides the distribution of crash and near-crash types for teenage drivers by sex (including all 285 crashes and near crashes for 42 teen drivers over all months). Males and females experienced similar numbers of crashes and near-crashes for almost every crash type. The teenage drivers had more crashes and near-crashes of every type as compared to the adult drivers. The most common types of crashes or near-crashes for both adult and teen drivers were conflict with a lead vehicle, conflict with an animal, conflict with a vehicle in the adjacent lane, and single vehicle conflict (accounting for 62 percent of the crashes and near-crashes for adult drivers and 69 percent for teen drivers).

4. Discussion

Initial findings reported in this paper indicate that the crash and near-crash experience of these novice drivers reflects national crash trends: (1) crash and near-crash rates were higher for teenage than adult participants, and (2) crash and near-crash rates among teenage participants were highest during the first six months of the study and declined steadily and significantly during the next 12 months. This is among the first papers to report a comparison of novice teenage crash and near-crash rates compared with adults driving the same vehicles. The findings match the national trends for novice driver crashes, and provide new evidence that the first year or so of driving is highly dangerous. Other findings include: (1) teenaged driving exposure averaged between 507 and 710 km (315–441 miles) per month over the study period, but varied substantially between participants with standard errors representing 8–14 percent of the mean; and (2) crash and near-crash types were very similar for male and female teenage drivers. As discussed below, these initial findings provide evidence that the teenage driver sample of the NTDS is similar to the US teenage driver pop-

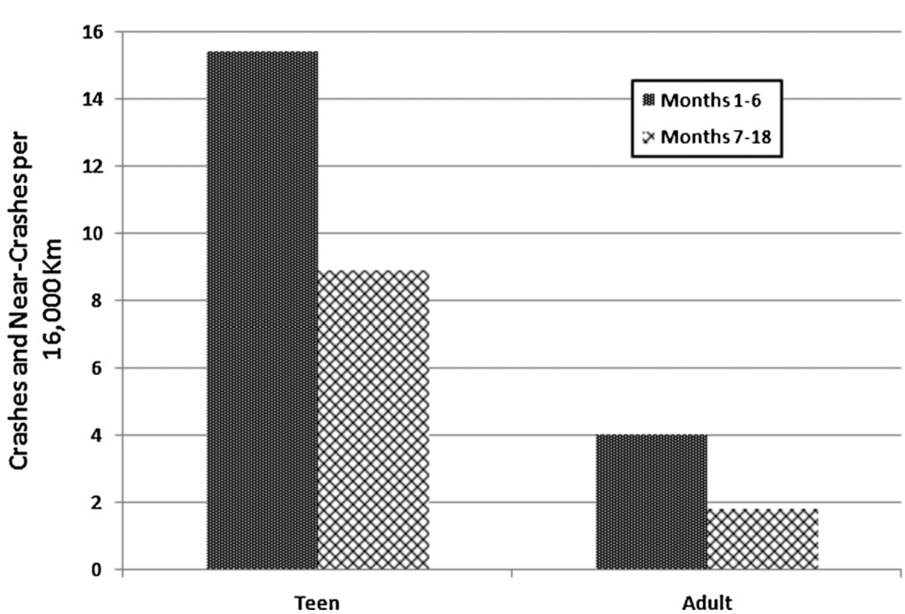

Fig. 3. Crashes and near-crashes (combined) per 16,000 km traveled for newly-licensed teen driver and adult participants.

Table 4
Crash and near-crash types for teenage drivers by sex.

Crash or near-crash type	Teen male		Teen female	
	Crash	Near-crash	Crash	Near-crash
Single vehicle conflict	9	27	16	17
Conflict with				
– Lead vehicle	0	39	1	27
– Animal	0	23	2	12
– Vehicle in adjacent lane	0	4	1	18
– Oncoming traffic	0	2	0	13
– Vehicle moving across subject path (through intersection)	0	3	0	9
– Vehicle turning across subject vehicle path (opposite direction)	0	2	0	11
– Obstacle/object in roadway	2	7	2	0
– Pedestrians	0	5	1	4
– Following vehicle	2	2	2	3
– Vehicle turning into subject vehicle path (same direction)	0	2	0	7
– Merging vehicle	0	2	0	3
Other[a]	0	3	0	2
Total	13	121	25	126

[a] Other includes conflict with pedal cyclist, parked vehicle, vehicle turning into subject vehicle path (opposite direction), and vehicle turning across subject vehicle path (same direction).

ulation in terms of exposure and crash experience, suggesting that they may generalize to the US population.

4.1. Crash and near-crash involvement

This is the first naturalistic study to report that crash rates were significantly higher for teenagers than adults, mostly parents, driving the same vehicle on mostly the same roads with an average of around 10 crashes or near-crashes per 16,000 km, compared with an average around 2 crashes or near-crashes per 16,000 km among adults.

This is also the first report from naturalistic data collection to demonstrate that rates of near-crashes and crashes were highest in the first six months of driving and declined from about 13.3/16,000 km to 8.5/16,000 km over the subsequent 12 months. The finding that crashes declined during the first year or so of driving has been previously reported in studies of crash reporting systems (based on police reports; e.g., Mayhew et al., 2003), and self-report (e.g., McCartt et al., 2003). The observed decline in crashes and near-crashes is consistent with the contention that driving risk declines only with many kilometers of independent (unsupervised) driving. Considering that the teenagers drove on average 590 km per month (366 miles), our data indicate that crash risk adjusted for kilometers driven was highly elevated during the first six months and declined after about 3500 km (2200 miles) and continued to decline for another 7000 km (6600 miles), obtained on average after 18 months of independent driving. This is similar to the estimate provided by McCartt et al. (2003).

The evaluation of near-crashes is one of the salient advantages of the naturalistic methods employed. Dingus et al. (2006) demonstrated that near-crashes are an appropriate safety surrogate for actual crashes in that they invariably reflect similar errors in driving judgment and result in extremes in driving performance (Dingus et al., 2006). Near-crashes can thus be combined with crashes in future analyses of risk, providing a much larger sample of events and more precise assessment of crash experience and driving performance than would otherwise be available. Although none of the crashes observed in this study was police-reported (assessment made by crash severity, video review, and self-report), the crash and near-crash categories were fairly consistent with police-reported crashes reported by Braitman et al. (2008). For example, Braitman et al. reported that 23 percent of police-reported crashes were a violation of the right-of-way, as compared to 30 percent of the crashes and near-crashes in the present study; rear-end crashes were 35 percent for Braitman et al. and 24 percent in this study; and run-off-road crashes were 30 percent for Braitman et al. and 25 percent in the current study. These similarities provide additional support for the notion that the crashes and near-crashes observed in the NTDS can be combined for analyses.

Our data indicated no differences between teenage males and females in crash and near-crash involvement. This is inconsistent with data on fatal crashes, which shows that males have much higher rates than females, but consistent with data for non-fatal crashes that show only small differences between teenage males and females (Williams, 2003; McCartt et al., 2003).

4.2. Exposure

This paper presents the first observation in real-time on driving exposure during the first 18 months of licensure for a sample of novice teenagers. Previous estimates of exposure were based on self-report studies (e.g., McCartt et al., 2003) or estimated from large scale self report data sources such as the National Household Transportation Survey (NHTS, 2010). The naturalistic driving technology employed provided precise measures of kilometers driven in the instrumented vehicles, allowing precise calculation of crash rates. Our findings that average exposure was 547 km (340 miles) per month in the first six months, growing to just over 619 km (384 miles) per months 12–18, is slightly lower than the available self reported estimates (e.g., McCartt et al., 2003). However, previous naturalistic studies (e.g., Dingus et al., 2006) have found that drivers overestimate their exposure (self-report as compared to sensor data on distance exposure for the same vehicle and driver). The wide variability within the sample is similar to that reported by Farmer et al. (2009). It is unclear if these findings are unique to the sample of small city/suburban youth, but the data provide one of the first reported, objective evaluations of driving exposure during the first 18 months of driving. During exit interviews, the teenage drivers reported that the majority of their driving was done in the instrumented vehicle, but it should be noted that any driving they did in other vehicles was not captured as part of this study. It should also be noted that gasoline prices fluctuated drastically during the study, especially during the last few months.

4.3. Future analyses

This paper provides broad results on crash and near-crash experience and exposure and lays the groundwork for future in-depth analyses of both of these items. The database resulting from this study is quite rich and expansive, and the opportunities for detailed future research on measures beyond crashes and near crashes and exposure are plentiful. Examples of these measures include driver error while merging, negotiating intersections, or traversing straight road segments; secondary task use during various driving conditions; eyeglance patterns during various driving situations; crash and near crash risk for various risk driving situations; patterns of driving significantly faster than the posted speed limit; and patterns of extreme kinematic maneuvers. One interesting aspect of these outcomes is that they might be expected to change significantly over time for the novice teenage drivers, but not for the adults. This is in contrast to other naturalistic studies which have included only experienced adult drivers whose performance would be expected to be relatively stable over time.

4.4. Study challenges and limitations

4.4.1. Driving exposure

For many outcomes of interest, useful analyses should control for exposure and most measures are best expressed as rates, where the number of events is the numerator and a measure of exposure is the denominator. Uneven exposure poses no problem for calculating rates, but will be accounted for in future analyses. For example, to evaluate crash rates by subgroups, such as high kilometers vs. low kilometers drivers, who might be different in ways other than exposure, covariates may need to be added as control variables in regression and other analyses. Similarly, uneven driving exposure may pose a problem in analyses of rates by driver and passenger characteristics and it may be necessary to examine the trends over periods of several months (thereby providing greater exposure) rather than monthly.

During the exit interview, almost all teenage participants estimated that they drove the instrumented vehicle for the vast majority of their trips. However, there is no way to know what proportion of their driving used the instrumented vehicle (rather than other family vehicles). It is possible that teenagers sometimes drove another uninstrumented vehicle and that valuable data were thus left out of the database.

4.4.2. Data challenges

A large amount of data was collected in the NTDS and substantial resources are required to evaluate the video and other data collected for the events. Because the participating vehicles were shared among family members, the video for every trip was viewed and coded. Many research questions relating to driving risk require identification of the driver and the conditions under which that person was driving for each trip (e.g., with or without passengers, day vs. night). For other analyses, efficient data reduction (identification of events and exposure of interest) is performed by computer algorithms for kinematic data triggers (flags placed in the data whenever a kinematic trigger is exceeded), geospatial sampling (using GPS data to identify times when a driver passed through a point of interest, such as a particular merge ramp or intersection), and data sampling (use of various sampling schemes to obtain either baseline or exposure data). Advances in naturalistic data collection technology designed to automate some time-intensive analyses (e.g., eye tracking) would be crucial for larger studies.

4.4.3. Unplanned interactions

The initial plan was to refrain from interacting with participants except for scheduled situations so that participants would not be reminded more often than necessary of their participation in the study. From the beginning, teenage and adult participants were informed that the data would not be shared with the teen's parents (and no such requests were made by parents). However, certain behaviors were observed in watching the videos that resulted in three unplanned interactions being held with participants, informing them of the behaviors that had been observed, and counseling to refrain from these behaviors at the risk of being removed from the study. Two of the interventions were directed toward observed alcohol or drug use, accompanied by impaired driving, and one intervention was directed toward a participant who allowed a much younger sibling drive the vehicle. IRB permission was obtained for these interventions, which seemed to be well-received by the participants. According to our ethics protocol, parents were not informed of either the behaviors or the interactions.

4.4.4. Study sample

Recruitment was somewhat difficult, primarily due to the fairly stringent eligibility criteria regarding licensure date. Ultimately, this participant sample was one of convenience, since all participants were volunteers who were willing to be observed while driving. There was some socio-economic bias built into the study design, in that eligible participants had to have access to an insured vehicle suitable for instrumentation. Average household income for all participants was thus high at slightly over $100,000, compared to median household income of $53,000 in Roanoke County and $35,000 in Montgomery County. Study participants could have been more likely to belong to higher socio-economic groups because these are the families who could afford to let their children drive from the time they were eligible; vehicle, insurance, and gas costs for teenage drivers can be prohibitive for lower income families.

Most participants were white, mirroring the demographics of the areas where the study was conducted. Montgomery and Roanoke Counties are about 90–92 percent white, 4–5 percent black, 2–5 percent Asian, and about 2 percent Hispanic. Population density in terms of people per square kilometers provides a surrogate measure for traffic density. The population density for Montgomery County is 73, as compared to 122 for Roanoke County and 86 for the United States (this is an average of all counties in the United States). The small size and voluntary nature of the sample suggests that the findings should be generalized with caution.

5. Conclusions

This paper presented the methods employed in the NTDS and initial findings on teenage driver crash and near crash experience. The rates of crashes and near-crashes were significantly higher among novices than among adults; higher among novices in the first six months compared the next 12 months; and declined over the first 12 months, while crash and near-crash rates among adults were stable over time. This is the first US study to report crash and near-crash rates of novice teenagers and adults driving the same vehicles over the same study period. Overall driving exposure varied considerably within the sample over time. The study obtained a wealth of naturalistic data on exposure, driving performance, and crashes and near-crashes that will enable study of many important questions about the nature of teenage driving during the first 18 months of licensure.

The public health implication of these findings is that additional solutions are urgently needed to reduce the high crash risk during the first year or so of driving. Driving education programs in their current form have not been demonstrated to provide protective effects, and while Graduated Driver Licensing programs have been demonstrated to reduce crash rates among novices (e.g., Chen et al., 2006), few of these programs include all recommended characteristics (McCartt et al., 2009), and there is considerable variability in the effectiveness of these programs based on their provisions (Chen et al., 2006). Parent management programs that encourage parents to limit the novice teen driving during the first year to lower-risk driving conditions while they gain independent driving experience can complement the effects of GDL (e.g., Simons-Morton et al., 2008); however, these programs are only now being implemented widely. Clearly, a great deal of additional work needs to be done.

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