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Variability in Crash and Near-Crash Risk among Novice Teenage Drivers: A Naturalistic Study

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Abstract

Objective—Using video monitoring technologies, we investigated teenage driving risk variation during the first 18 months of independent driving.

Study design—Driving data were collected on 42 teenagers whose vehicles were instrumented with sophisticated video and data recording devices. Surveys on demographic and personality characteristics were administered at baseline. Drivers were classified into three risk groups using a K-mean clustering method based on crash and near-crash (CNC) rate. The change in CNC rates over time was evaluated by mixed-effect Poisson models.

Results—Compared with the first three months after licensure (first quarter), the CNC rate for participants during the third, fourth and fifth quarters decreased significantly to 59%, 62%, and 48%, respectively. Three distinct risk groups were identified with CNC rates of 21.8 (high-risk), 8.3 (moderate-risk), and 2.1 (low-risk) per 10000 kilometers traveled. High- and low-risk drivers showed no significant change in CNC rates throughout the 18-month study period. CNC rates for moderate-risk drivers decreased substantially from 8.8 per 10000 kilometers in the first quarter to 0.8 and 3.2 in the fourth and fifth quarters, respectively. The three groups were not distinguishable with respect to personality characteristics.

Conclusion—Teenage CNC rates varied substantially, with distinct high-, moderate-, and low-risk groups. Risk declined over time only in the moderate-risk group. The high-risk drivers appeared to be insensitive to experience, with CNC rates consistently high throughout the 18-month study period, and the moderate-risk group appeared to learn from experience.

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Keywords

Naturalistic driving study; driving risk; novice driver; teenage drivers; adolescents; learning; driving experience

Motor vehicle crash risk is higher for teenage drivers than for older age groups. In the United States in 2009 the rate of fatal crashes per 100 000 licensed drivers was 39.1 for 15 to 20 year olds, compared with 32.7 for age group 21 to 24 and 23.7 for age group 25 to 34 years.[1] Previous studies have shown that the first few months of driving after licensure are the most dangerous.[2] Crash rates decline during the first years of licensed driving but remain much higher compared with experienced adults older than 25 years.[3] However, driving risk may not be evenly distributed in the population of young drivers. Previous studies of young drivers have shown the existence of subgroups of drivers at different risk levels, with some drivers having a much higher risk than others.[4, 5]

Teenage driving risk could be affected by various factors. Simulation, test track, and observational studies have shown that novice and young drivers have poorly developed driving skills and are prone to distraction[6–8]. Studies using epidemiologic and observational methods indicate that crash rates and risky behavior among teenage drivers are higher for males than for females, at night, and in the presence of passengers. [3, 9, 10] Crash risk has been associated with certain personality characteristics, such as sensation seeking and some of the NEO-Five personality inventory factors (eg, extraversion, agreeableness, and conscientiousness) in systematic literature review, [11, 12] which may partially differentiate risk groups. [4, 13]

The Naturalistic Teenage Driving Study (NTDS) used continuous video and data recoding techniques to evaluate driving risk of novice teenage drivers.[14] The high resolution data collected through naturalistic studies provide objective information about crash events and risk factors.[15] The method is particularly valuable for studying novice teenage drivers whose driving performance can be expected to change substantially during the initial months after licensing. Previous findings from the NTDS showed that despite significant declines in crash and near crash rates over the 18-month study period, risk among novice teenage drivers was significantly higher than adults over the entire study period.[16, 17]

The purpose of the present study is to examine the variation in risk among novice teenage drivers, specifically the change in crash and near-crash (CNC) rate over time by risk group and to evaluate the demographic, driving conditions, and personality characteristics of risk groups.

METHODS

Forty-two teenage drivers from the New River Valley and Roanoke areas of the Commonwealth of Virginia in the United States were recruited within three weeks after licensure and followed for 18 months using methods described by Lee et al.[14] Study participants included 22 females and 20 males with a mean age of 16.4 years (standard deviation = 0.33). Teenage participant assent and parent consent were obtained, and teens were provided incentives according to procedures approved by the Virginia Tech Institutional Review Board. A Certificate of Confidentiality was also obtained from the US Department of Health and Human Services to further protect the participants' privacy and data.

The vehicles of the participants were instrumented with an advanced data acquisition system developed by the Virginia Tech Transportation Institute with four video cameras, a Global

Positioning System, radars, a three-dimensional accelerometer, a speedometer, and other sensors.[14] Participants were instructed to drive as they would normally. The teenage participants and their parents did not have access to the data and no feedback was provided. The camera views monitored 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 area. The data acquisition system also recorded radar, GPS, vehicle network, and kinematic data, including speed and three-dimensional acceleration etc.[14] The video and driving performance data were continuously recorded at 10 Hz (10 data points per second). Data were stored on the onboard hard drive and later downloaded to a secure central database for analyses. Audio during driving was not recorded. All participants were aware of the recording equipment in the vehicles. Previous studies have demonstrated that drivers quickly forget about the recording equipment, and exhibit very natural driving and non-driving behaviors, often within the first hour. [15]

Coders reviewed the video data for each trip and noted a wide spectrum of trip-based information including driver identity and passenger presence. The data coding followed a standardized and rigorous protocol developed in previous studies to ensure the accuracy and reliability of information.[14] Trip length and duration, including total distance traveled, percentage of distance traveled at night, length of individual trip, percentage of trips traveled by passenger status, were calculated using automated computer algorithms.

A baseline questionnaire survey was administered including demographic information, vehicle sharing status, and two measures of personality. The NEO-Five Factor Inventory Questionnaire Form S is a 60-item questionnaire with five subscales: neuroticism, extraversion, openness to experience, agreeableness, conscientiousness.[18] Each subscale includes 12 questions with response choices ranging from "strongly disagree" to "strongly agree" and can have a score ranging from 0 to 48. Reported internal consistency of the NEO-FFI ranges from alpha = 0.68 for agreeableness to 0.86 for neuroticism, test-retest reliability is reported as r = 0.79 to r = 0.83, and acceptable convergent and discriminant validity have been demonstrated.[18] Predictive validity has been established with different outcomes, including college student GPA.[19] Sensation seeking was assessed with the 40-item Sensation Seeking Scale Form V.[20] The measure provided a global score and four subscales: thrill and adventure seeking, experience seeking, disinhibition, and boredom susceptibility. Each subscale consists of 10 questions each with a binary choice and can have a score between 0 and 10. The internal consistency alpha ranges from 0.55 for boredom susceptibility and 0.80 for the global score.[20] Studies have demonstrated the association between sensation seeking scale and different behaviors, including risk driving. [21]

Two types of safety critical events, crashes and near-crashes, were assessed. A crash was defined by Lee et al[14] as "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." The definition of near-crash was as follows: "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." Crashes and near-crashes were identified by kinematic triggers (eg, harsh braking ≤−0.65 g; Lee et al [14] for the full list) followed by visual verification. By definition, near-crashes are safety critical events that threaten safety and should be avoided. Given the generally small number of participants in naturalistic driving studies, combining crashes and near-crashes provides considerable analytic advantages and is widely adopted in naturalistic driving study analyses.[22, 23]

Statistical Analyses

Participants were classified into risk groups based on overall CNC rates during the entire study period. A K-mean cluster method was used to provide an objective classification by partitioning participants into pre-defined K-clusters by minimizing the within-cluster variations.

Depending on specific metrics, the demographic, driving, and personality characteristics of the risk groups were compared using an analysis of variance method or the Cochran-Mantel-Haenszel test.

A mixed-effect Poisson regression approach was used to model CNC rates. The model assumption is that CNC counts are generated from a Poisson process, and the subject-specific effects are incorporated through a random effect term.

RESULTS

During the 18 months of data collection teenage study participants drove more than 71 000 trips involving approximately 435 000 kilometers (km) and 10 676 hours traveled, an average of about 6 400 km a year.[24] Safety belts were used in over 90% of trips. A total of 37 crashes and 242 near-crashes were identified. Most crashes were single-vehicle conflict, and most near-crashes included single-vehicle conflicts and conflicts with lead vehicles, animals, or vehicles in the adjacent lane.[14] The CNC rate was measured by the number of CNC events per 10 000 km traveled (10K kmt).

Driver Risk Classification

The distribution of CNC rate for the 18-month study period by driver was highly skewed (Figure 1). Considering the relatively small sample size and the non-interpretability of results using many groups, a target of three clusters was established. Because the K-mean cluster method is sensitive to outliers, two participants with the highest CNC rates were excluded from the initial cluster analysis and were added to the high-risk group later. The clustering analyses resulted in 13 participants in the low-risk group (<6.5 CNCs per 10K kmt), 16 in the moderate-risk group (6.5 to 21 CNCs per 10K kmt), and 13 in the high-risk group (>21 CNCs per 10K kmt) (Figure 1). The average CNC rates for the three groups during the entire 18-month study period were 2.1, 8.3, and 21.8 per 10K kmt, respectively. The high-risk group accounted for nearly 60% of CNC events (166 out of 279) but only 26% of the total mileage. In contrast, the low-risk group accounted for 9% of CNC events and 35% of the total mileage.

Differences in CNC Rates by Time since Licensure

To account for uneven distribution of safety critical events, mileage across participants, and small sample size, data were aggregated by three-month clusters. For all participants combined, the CNC rate decreased consistently through months 13–15 (Table I). The first quarter of independent driving was the most dangerous period, with an average CNC rate of 9.2 per 10K kmt for all drivers. To assess safety improvement over time, CNC rates in other quarters were compared with the first quarter. The output of the mixed-effect Poisson model indicated that beginning in the third quarter CNC rates were significantly lower than the first quarter. The CNC rate in the third quarter for all drivers decreased to 59% of the first quarter (rate ratio = 0.59, 95% CI = [0.40, 0.88]). The CNC rate in the fourth quarter was 62% (rate ratio = 0.62, 95% CI = [0.42,0.92]) and in the fifth quarter 48% (rate ratio = 0.48, 95% CI = [0.31,0.74]) of the first quarter, respectively. Therefore, CNC risk declined over time for the study group.

The CNC rates by risk group and time in quarters provided in Table I are illustrated in Figure 2. As shown, the pattern of CNC rates over time differed substantially by risk group. For low-risk drivers the CNC rate was relatively low and stable for the first 18 months, with an average less than 2 per 10K kmt.

The most notable pattern of change was observed for moderate-risk drivers. The CNC rate in the initial six months for the moderate-risk group was more than four times higher than the low-risk group and slightly lower than the high-risk group (without outliers). The CNC rate dropped substantially thereafter from 8.8 during the first quarter to 4.8 during the third quarter and then to 0.8 during the fourth quarter. The CNC rates in the fourth and fifth quarters were lower than the first quarter with CNC rate ratios of 0.09 (95% CI = [0.02, 0.37]) and 0.36 (95% CI = [0.17, 0.78]) respectively. Despite the substantial decline over time, rates for the moderate-risk group were consistently higher than that of the low-risk group except in the fourth quarter.

CNC rates for the high-risk group without the two outliers did not decline over time and remained high during the entire 18-month study period. Rates for the risky driver group with the two outliers were extremely high at the onset (19.8 CNC events per 10K kmt during the first quarter), declined significantly only during the third quarter (rate ratio = 0.59, 95% CI = [0.35,0.98]), and remained generally high over the remaining quarters.

Characteristics of the Risk Groups

Sex, average kilometers traveled, vehicle-sharing status, distribution of trip length, percentage of kilometers traveled by passenger type and during nighttime, and personality characteristics were evaluated by risk groups.

The percentage of kilometers driven with adult passengers for the low-risk group was nearly three times higher than that for the moderate- and high-risk groups (15.5% versus 6.0% and 5.1% respectively; Table II). The low-risk group also traveled less with no passengers (51.7% km traveled alone versus 65.5% and 62.2% for moderate- and high-risk group, respectively).

The low-risk group also had a low percentage of mileage traveled during short trips (59.0%) compared with moderate- (71.1%) and high-risk (76.2%) groups with a significant difference between low- and high-risk groups. This result is consistent with the finding that CNC rate on trips shorter than 15 km is significantly higher than that of trips longer than 30 km (CNC rate ratio = 2.50, 95% CI = [1.48, 4.20], p-value<0.001).

No significant between-group differences were found for personality characteristics measured by the NEO-Five Factor Inventory Questionnaire Form S and the Sensation Seeking Scale Form V.[20]

DISCUSSION

The NTDS, a longitudinal, robust, naturalistic driving study with focus on novice teenagers, provided an unprecedented opportunity to evaluate the patterns of driving risk over the first 18 months of licensure. This study indicated that CNC risk varied substantially among teenage driver risk groups. The mean CNC rate of the high-risk group (21.8 CNCs per 10K kmt) was 10.6 times higher than the low-risk group (2.1) and 2.6 times higher than the moderate-risk group (8.3). Although crash risk may be elevated for novice drivers in general, our findings indicate that risk was not evenly distributed. This finding is consistent with other research that has shown a high propensity for risk in subsamples of

drivers.[4, 5, 15, 25–27] Our findings support the existence of different risk subgroups at early stages of independent driving.

The most striking finding of this study is the distinct patterns of CNC rate over time by risk groups. Several previous studies have reported rapid declines in crash risk during the first 6 months of licensed driving, including one using the NTDS data[3, 16], however, no previous study demonstrated variability in this decline by risk group. In our study the overall risk decrease observed for all drivers is due primarily to the moderate-risk group; both low- and high-risk groups having stable CNC rates during the study period. In contrast, the CNC rate for the moderate-risk group decreased tenfold in the first 18 months after licensure. It appears that the moderate-risk group improved the most from experience and their CNC patterns reflected the classic learning curve for complex psychomotor skills (eg, many errors occurring early followed by a rapid decline) as described by Elvik. [28] We speculate that this group learned from their driving experience to manage risk. Of course, experience is confounded by age and maturity, so it cannot be stated with certainty that change over time was due entirely to experience, but by definition improvements in CNC rates reflect learning. In vivid contrast, the high-risk group either failed to learn how to reduce their crash experience by improving their driving performance and better managing driving risk, or preferred to engage in risky driving behavior despite the higher risk of CNC. [16, 29] We speculate that drivers in the low-risk group had better driving skills or judgment, or otherwise were better able to managed driving risk relative to their driving skill than other novices in the study. Although we found no group differences in personality and there was little variability in age, the groups might have varied on factors not measured in this study, for example, biological development/maturation, parent management of teen driving, or driving safety culture of the family or peer group.

Systematic reviews of the literature have shown a relationship between sensation-seeking, personality characteristics and risky driving behavior and driving risk. [2, 30] In this study, although a monotonic decrease/increase was observed for the neuroticism, conscientiousness, and experience seeking scales of the risk groups, the differences were not statistically significant. It may be that the high-risk group was simply more careless, less attentive, deficient in driving judgment, developmentally less mature, rather than higher in sensation seeking propensity. Additional research is needed to confirm, distinguish, and better understand driving risk groups, such as found in this study.

Some variability in driving conditions was found. Compared with the low-risk group, the high-risk group traveled a lower proportion of kilometers with adult passengers and a greater proportion of short trips. The low-risk group also traveled less alone compared with the moderate-risk group. Although it cannot be determined if these factors were causal, the low percentage of kilometers traveled with parents may reflect lower levels of parental involvement and less parental management for the high-risk group. Previous research has shown that novice teenagers whose parents set limits on their driving engage in less risky driving behavior, and parents who ride at least occasionally with their newly-licensed teenage drivers would have opportunities to establish expectations and set standards that could carry over to independent teenage driving. [31]

The study is limited by the voluntary regional sample and small sample size that provided limited power for detecting group differences. Even though the validity of combining crashes and near-crashes has been demonstrated previously [22, 32], most of the crashes in the NTDS sample were minor, with only four being reported to the police and one involving minor injuries.

We place our findings within the context of what is known about crash prevention among novice drivers. Notably, there is little evidence that pre-license training and practice affect independent driving safety, but ample evidence that post-licensure driving experience, graduated driver license policies, and parental management reduce risk. [31,32] Graduated driver licensing provisions and parental management practices can limit the highest driving-risk conditions while teens develop safe driving skills and judgment, and limiting exposure would be expected to provide safety benefits to low-, moderate-, and high-risk drivers.

Findings from this study indicate that critical incident rates varied substantially among novice teenage drivers, but the conclusion should be resisted that the crash risk of a particular teen or group of teenagers can be known in advance, at least based on the personality and other the factors evaluated in this study. Given the generally high crash risk, particularly of the high-risk group, and the lack of identified individual factors, we believe the findings provide support for strict graduated driver licensing policies and improved parental management practices that limit the driving conditions of newly licensed drivers. [29]

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ABBREVIATION

10K kmt	10 000 km traveled
CNC	Crash and near-crash
km	Kilometers
NTDS	Naturalistic teenage driving study

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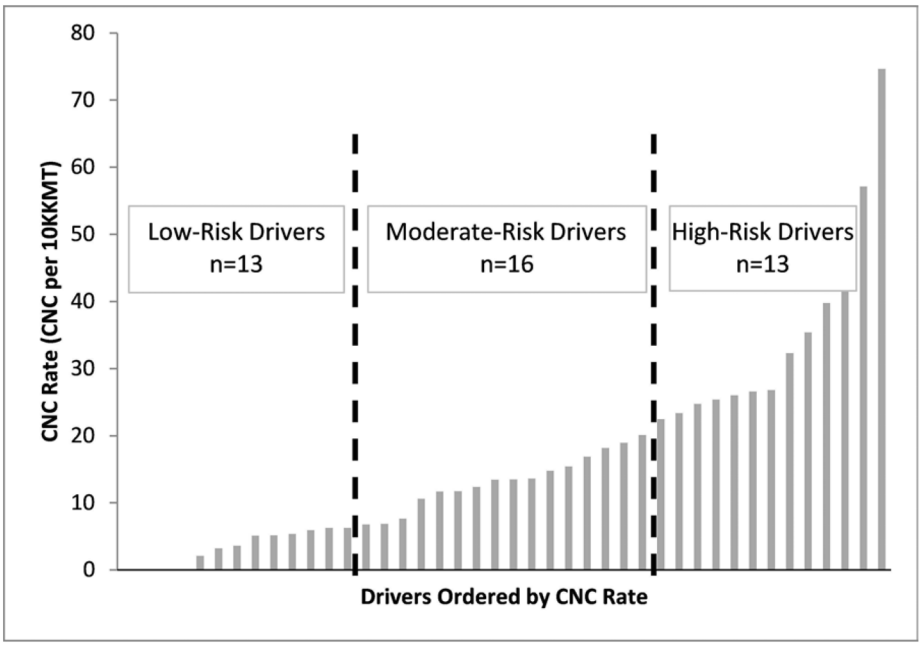

Figure 1.
Distribution of total CNC rates per quarter over 18 months by driver risk group (n = 42). Four participants in the low-risk group had zero CNC and cannot be shown in the plot.

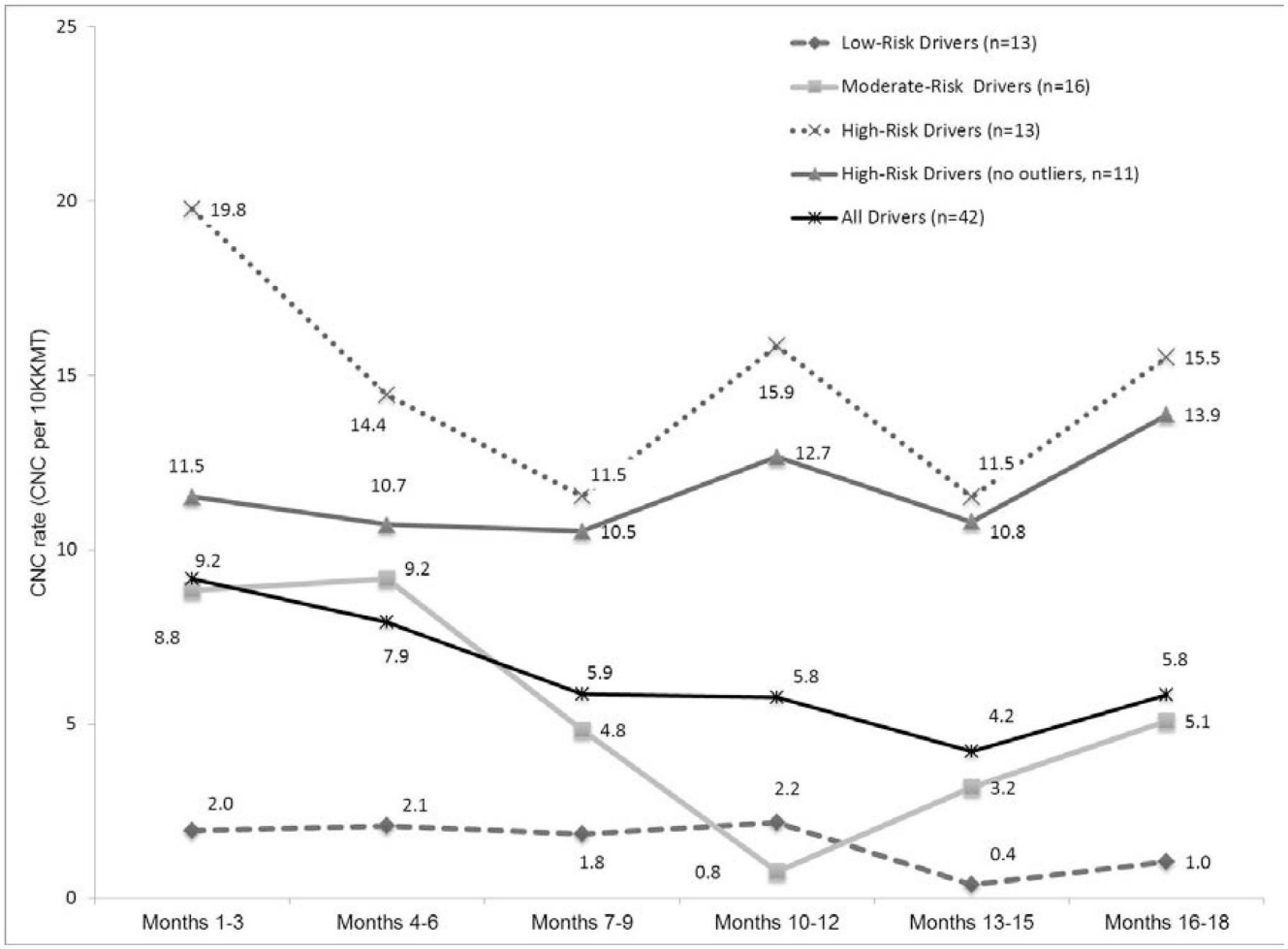

Figure 2.
CNC rate variations by 3-month clusters and by risk groups (n = 42).

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Table 1

CNC Rates per 10 000 Kilometers Traveled by Three-Month Clusters (n = 42)

Driver Group	Months since Licensure	Kilometers (thousand)	CNC Count	CNC Rate (per 10KKMT)	Rate Ratio: CNC Rate during Other Periods versus Month 1–3 (Mixed-effect Poisson Models)	
					Rate Ratio and 95% CI	P-value
Overall	1–3	69.9	64	9.2	•	•
	4–6	66.8	53	7.9	0.86 (0.60,1.24)	0.42
	7–9	71.5	42	5.9	**0.59 (0.40,0.88)**	**<0.01**
	10–12	76.4	44	5.8	**0.62 (0.42,0.92)**	**0.02**
	13–15	71.1	30	4.2	**0.48 (0.31,0.74)**	**<0.01**
	16–18	78.9	46	5.8	0.70 (0.48,1.03)	0.07
Low-Risk	1–3	25.6	5	1.9	•	•
	4–6	24.0	5	2.1	1.07 (0.31,3.69)	0.92
	7–9	21.7	4	1.8	0.94 (0.25,3.52)	0.93
	10–12	27.5	6	2.2	1.12 (0.34,3.67)	0.85
	13–15	25.5	1	0.4	0.20 (0.02,1.72)	0.14
	16–18	28.7	3	1.0	0.54 (0.13,2.24)	0.39
Moderate-Risk	1–3	26.0	23	8.8	•	•
	4–6	26.2	24	9.2	1.04 (0.58,1.84)	0.90
	7–9	29.0	14	4.8	0.55 (0.28,1.06)	0.08
	10–12	26.2	2	0.8	**0.09 (0.02,0.37)**	**<0.01**
	13–15	28.2	9	3.2	**0.36 (0.17,0.78)**	**<0.01**
	16–18	33.4	17	5.1	0.57 (0.31,1.08)	0.08
High-Risk (excluding outliers)	1–3	13.9	16	11.5	•	•
	4–6	12.1	13	10.7	0.93 (0.45,1.94)	0.85
	7–9	16.1	17	10.5	0.91 (0.46,1.81)	0.80
	10–12	19.7	25	12.7	1.10 (0.59,2.06)	0.77
	13–15	13.9	15	10.8	0.94 (0.46,1.90)	0.86
	16–18	13.7	19	13.9	1.20 (0.62,2.34)	0.59
High-Risk	1–3	18.2	36	19.8	•	•
	4–6	16.6	24	14.4	0.72 (0.43,1.21)	0.21
	7–9	20.8	24	11.5	**0.59 (0.35,0.98)**	**0.04**

Driver Group	Months since Licensure	Kilometers (thousand)	CNC Count	CNC Rate (per 10KKMT)	Rate Ratio: CNC Rate during Other Periods versus Month 1–3 (Mixed-effect Poisson Models)	
					Rate Ratio and 95% CI	P-value
	10–12	22.7	36	15.9	0.86 (0.54,1.37)	0.52
	13–15	17.4	20	11.5	0.61 (0.35,1.06)	0.08
	16–18	16.7	26	15.5	0.83 (0.50,1.39)	0.49

Table II

Demographic, Driving and Personality Characteristics of the Low-, Moderate- and High-Risk Groups (n = 42)

	Low- Risk Drivers (n = 13)	Moderate-Risk Drivers (n = 16)	High-Risk Drivers (n = 13)	P-values
CNC rate (per 10K kmt)	2.1 (1.6 [6])	8.3 (2.5)	21.8(9.6)	N/A
Frequency of CNC	24	89	166	N/A
Sex (% of males)[1]	53.8	38.9	42.6	0.70
Vehicle sharing (% with own vehicles)[1]	46.2	68.8	69.2	0.23
Total distance traveled per driver (1000 km)[2]	11.8 (6.6)	10.6 (4.2)	8.6 (3.5)	0.27
Passenger[2] (average % of km)				
Driven alone	51.7 (21.1)	65.5 (12.7)	62.2 (15.2)	0.08[3]
With teen passenger	25.5 (16.3)	22.5 (12.5)	26.9 (11.2)	0.66
With adult passenger	15.5 (21.9)	6.0 (6.7)	5.1 (5.2)	0.09[4]
Nighttime driving[2]				
% of KM traveled at night	20.3 (8.3)	23.5 (8.7)	24.2 (10.7)	0.53
Trip length[2] (Average % of KMs)				
By trips <=15 KM	59.0 (27.5)	71.1 (16.4)	76.2 (13.6)	0.09[5]
By trips >15KM <=30 KM	19.7 (13.2)	18.9 (10.3)	14.4 (8.4)	0.40
By trips >30KM	21.3 (25.6)	10.2 (7.6)	9.4 (7.6)	0.10
NEO 5 traits[2] (average score)				
Agreeableness	33.3 (4.6)	30.1 (7.3)	31.8 (5.1)	0.38
Conscientiousness	32.9 (5.1)	28.9 (7.3)	27.9 (6.1)	0.13
Extraversion	28.9 (5.4)	30.9 (6.7)	30.7 (4.6)	0.61
Neuroticism	16.1 (6.0)	19.6 (7.3)	20.9 (10.3)	0.29
Openness to Experience	27.8 (5.5)	26.8 (6.0)	28.5 (7.6)	0.75
Sensation seeking[2] (average score)				
Overall Score	14.1 (7.1)	15.7 (6.7)	15.5 (7.5)	0.84
Thrill and Adventure Seeking	6.5 (2.7)	6.4 (3.2)	6.3 (2.8)	0.99
Boredom Susceptibility	2.4 (2.2)	3.1 (2.0)	2.5 (2.1)	0.45
Experience Seeking	2.9 (1.5)	4.0 (2.0)	4.3 (2.8)	0.19
Disinhibition	3.2 (3.4)	2.3 (2.2)	2.3 (2.0)	0.72

[1] Cochran-Mantel-Haenszel test for non-zero correlation

[2] Analysis of variance

[3] There is significant difference in % of km driven alone between low- and moderate-risk groups (p-value is 0.03).

[4] There is a marginal significant difference in % of km driven with adult passengers between low- and high-risk groups (p-value is 0.05).

[5] There is a significant difference in % of km traveled by short trip between low- and high-risk groups (p-value = 0.03).

[6] The number in parenthesis is the SD