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Learner Driver Experience and Teenagers' Crash Risk During the First Year of Independent Driving

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IMPORTANCE One mechanism for teenagers' elevated crash risk during independent driving may be inadequate learner driving experience.

OBJECTIVE To determine how learner driver experience was associated with crash risk during the first year of independent driving.

DESIGN, SETTING, AND PARTICIPANTS Youth aged 15.5 to 16.1 years at recruitment were eligible to participate. Participants' vehicles were instrumented with sensors, and driving was recorded during the learner period through 1 year of independent driving. Data were collected from January 2011 through August 2014 in southwestern Virginia.

EXPOSURES The amount, consistency and variety of practice, driving errors, and kinematic risky driving (KRD) rates during the learner period were recorded. Surveys, including one on sensation-seeking personality traits, were assessed at baseline.

MAIN OUTCOMES AND MEASURES Cox proportional hazard regressions examined associations between individual characteristics and learner driving experience with driving time to first crash and all crashes in the first year of independent driving. So that hazard ratios (HRs) can be directly comparable, units of measurement were standardized to the interquartile range.

RESULTS Of 298 individuals who responded to recruitment, 90 fulfilled the criteria and 82 completed the study (of whom 75 were white [91%] and 44 were girls [54%]). Teenage participants drove a mean (SD) of 1259.2 (939.7) miles over 89 days during the learner period. There were 49 property-damage crashes and/or police-reportable crashes during independent driving. Factors associated with driving time to first crash included higher sensation-seeking personality scale scores (HR, 1.67 [95% CI, 1.08-2.57] per 0.75-unit increase), learner driving KRD rates (HR, 1.27 [95% CI, 1.12-1.43] per 9.24-unit increase), and learner driving errors (HR, 0.44 [95% CI, 0.22-0.86] per increase of 6.48 errors). Similar results were obtained for all crashes in the first year, with the addition of consistency of learner driving practice (HR, 0.61 [95% CI, 0.38-0.99] per 0.23-unit increase).

CONCLUSIONS AND RELEVANCE Individual characteristics and learner driving experiences were associated with crash risk during independent driving. As expected, there was an association between sensation seeking and crashes. Elevated KRD rates during the learner period may reflect risky driving behavior among novices or tolerance to abrupt maneuvers by parents who supervise driving. Consistent practice throughout the learner period could reduce teenage crash risk, which is supported by learning theories indicating distributed practice is effective for developing expertise. Errors during practice may constitute learning events that reinforce safer driving. Physicians could encourage parents to provide opportunities for regular practice driving and monitor their teenager's KRD rates during the learner period using in-vehicle or smartphone-based technology.

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Supplemental content

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An enduring question for parents of teenage drivers, pediatricians, and policy makers is what can be done during the learner period of graduated driver licensing (GDL) to maximize teenage drivers' safety during the first years of independent driving, when crash risk is highest.[1,2] The prolonged learner period is intended to provide opportunities for extended practice and for parents to prepare teenagers for safe independent driving. Despite the fact that a learner period is required as part of GDL for teenage drivers in every US state, surprisingly little is known about whether practice is conducive to the development of safe driving skills and, if so, which elements might be associated with a reduction in crash risk during independent driving.[3] Basic questions, such as the optimal number of months a learner license should be held,[4] the amount of driving experience (in miles or hours driven) during the learner period that confers a safety benefit,[5] and what actually happens during practice driving, such as the instruction provided by parents and their approaches to dealing with their teenagers' driving errors or risky driving,[6] are not well understood.[7]

The small body of research examining the question of what can be done during the learner period to promote safety during the first years of independent driving has methodological weaknesses and is inconclusive. A New Zealand study (N = 3992) found that teenagers' self-reported crash risk during independent driving was reduced the longer teenagers remained on their learner license beyond the minimum requirement (relative risk, 0.63 [95% CI, 0.43-091]).[8] In a sample of teenagers in Queensland, Australia (N = 1032) who completed 100 hours of supervised practice as part of GDL, boys had significantly fewer traffic offenses and girls had lower self-reported crashes compared with teenagers who had no minimum practice requirement (0.6% vs 4.7% and 0% vs 6.6%, respectively).[9] In a US study (N = 911), the number of miles driven or the months that teenagers held their learner's permit were not associated with self-reported independent driving crash risk.[10] A study[11,12] of Swedish teenagers (N = 2457) who practiced for a mean of 120 hours during the learner period had significantly fewer crashes than those who had completed approximately 50 hours of practice (incidence ratio, 0.54 [95% CI, 0.50-0.59]), and learner drivers in a cohort study[13] in Great Britain (N = 11 083) who had 2 or more hours practice on busy town-center roads or in poor weather conditions had a lower self-reported crash risk relative to those with no practice under those conditions.

All studies just described were self-reported, retrospective, and assessed several months after the learner period had ended. While this provides the advantage of larger sample sizes, it comes with the limitation of imprecise estimates of how much driving occurred.[14] Few of the studies used an objective measure of how many times teenagers crashed. To our knowledge, none looked at the variety of driving experience or instruction,[7] driving errors, kinematic risky driving (KRD) during practice,[6] or how individual characteristics, such as personality,[15] might influence the association between learner driving experience and crash risk. The purpose of this study was to determine which elements of learner experience might influence safety outcomes during independent driving using objective measures of driving behavior, video footage capturing parental driving instruction, and surveys measuring individual characteristics.

Key Points

Question What can parents do during the learner period to reduce their teenagers' crash risk during the first year of independent driving?

Findings In this cohort study with 90 families, teenagers who practiced consistently and had lower abrupt maneuvering rates during the learner period had significantly fewer crashes during the first year of driving.

Meaning Per this analysis, parents can reduce teenagers' crash risk during the first year of independent driving by encouraging regular practice and discouraging driving behaviors that result in abrupt maneuvers.

Methods

The vehicles of 90 teenage drivers in southwestern Virginia were instrumented with data acquisition systems within 3 weeks of the youths' obtaining a learner's permit. In Virginia, drivers younger than 18 years must hold a learner's permit for at least 9 months and practice for at least 45 hours under the supervision of an adult with a driver's license.[16] Driving behavior from both the learner and independent driving periods was measured, including a minimum of 9 months during the learner period and up to 12 months of independent driving. Participants informed the study team when they obtained their independent driving license.

Selection Criteria

Participation of teenage drivers and at least 1 of their parents was required. Recruitment was conducted through local newspaper advertisements and high school visits in southwestern Virginia. Teenage participants were screened in a telephone interview for eligibility using the following inclusion criteria: (1) being between 15.5 and 16.1 years old; (2) holding a learner's driver's license for no more than 3 weeks; (3) having at least 20/40 best-corrected visual acuity; (4) having access to a vehicle for at least 18 months; (5) residing within a 1-hour drive of the research center; and (6) holding liability insurance on the vehicle to be used in the study (as required by state law). Parent participants were required to have (1) a valid US driver's license, vehicle insurance, and proof of ownership and (2) at least 1 of their vehicles equipped with the instrumentation required for the study. Participants were excluded for (1) having a diagnosis of attention-deficit disorder or attention-deficit/hyperactivity disorder, (2) having an identical twin, and (3) driving in restricted areas that do not allow cameras in vehicles. Recruitment was stratified by participant sex. Data were collected from January 2011 to August 2014.

Consent and Compensation

Parental consent and assent for teenagers' participation and an adult consent form for parent participation were ob-

tained. Teenagers received $800 for completing the study. The protocol was approved by the Virginia Polytechnic Institute and State University (Virginia Tech) institutional review board.

Vehicle Instrumentation

Data acquisition system included a computer that received and stored continuous data from accelerometers, a global positioning system, and cameras. Video cameras captured the driver's face, the dashboard, areas reachable by the driver's hands, and the forward and rear roadway. A microphone recorded in-vehicle conversations and driving instructions. Additional details about vehicle instrumentation has been described by Dingus and colleagues.[17]

Driving Exposure

A trip was defined as beginning when the vehicle ignition was turned on and ending when the ignition was turned off (time driven). A global positioning system recorded the distance traveled (miles driven). The number of days driven was measured by identifying trips occurring within 24-hour periods. A measure of driving consistency was derived by dividing the number of days driven during the learner's-permit period by the number of days the participants held their learner's permit. Sunrise and sunset times[18] and precipitation data were obtained from the National Oceanic and Atmospheric Administration[19] and merged with trip information.

Kinematic Risky Driving (KRD) Rates

Using an accelerometer, elevated gravitational forces (*g* forces) were measured during the learner and independent driving periods. Thresholds were set at the level shown to assess likely future crashes and near crashes among teenage drivers.[20] All *g* force event rates were calculated per 1000 miles, forming the KRD rate measure (details in the eMethods in the Supplement).

Crashes

Coders reviewed video footage corresponding to extreme *g* force events to identify crashes and near crashes. A crash was defined as any contact between the participant's vehicle and other object, either moving or fixed, at any speed. Crashes were further classified according to severity: minor crashes in which no damage occurred, property-damage crashes, and police-reportable crashes.

Video and Audio Data

Driving during the initial learner period (the first 10 hours of practice) and the late learner period (the final 10 hours) was systematically sampled as follows: a random 30-second clip was sampled from each consecutive 5-minute period of driving during the first and last 10 hours of practice, providing 240 observations per participant during the initial and late learner periods.

Data Coding

Five trained research assistants analyzed the video and audio data and categorized the topics and nature of driving instruction, driving errors, and secondary tasks and the road types that learners encountered during the learner period of driving. Coders were trained using a protocol, with the coding manager reviewing 100% of their work until the trainee coder achieved a high degree of accuracy (details in the eMethods and eResults in the Supplement).

Driving Instruction

Conversations occurring between parents and their teenage drivers in the sampled videos during the initial and late learner periods were categorized as associated with functional and higher-order instructions.[21] The total number of instructions was the mean of all observed driving instructions occurring during the initial and late learner periods.

Driving Errors and Secondary Tasks

Errors observed in the sampled videos during the initial and late learner periods were classified into 3 categories according to a system developed by the National Highway Transportation Safety Administration[22] and adapted by Curry and colleagues[23]: (1) recognition errors, (2) decision errors, and (3) performance errors. High-risk secondary tasks were also recorded.[24] Total driving errors were the mean number of error types observed during the initial and late learner periods.

Driving Variety

Roadway types observed in the sampled videos during the initial and late learner periods formed the basis of the measure of driving variety.[6] Total driving variety was the mean number of roadway types that were observed during the initial and late learner periods.

Survey Measures

The following scales were administered to teenagers at baseline: the Hoyle Brief Sensation-Seeking Personality Measure,[25] Friends Risk-Taking Behavior,[26] Parental Trust,[27] Parental Knowledge of Teenagers' Lives,[27] Parental Restrictions Related to Driving,[28] and Pre-permit Driving Experience, which measured the frequency and types of vehicles teenagers had driven prior to receiving a learner's permit (details in the eMethods and eTable in the Supplement).

Analysis

Many clinical outcomes, including crashes, recur in the same individual. However, crash-risk studies typically use time to first crash as the outcome, ignoring recurring events.[29] In these analyses, we included all crashes for each individual in the first year of independent driving. We used a Cox proportional hazard regression model to assess associations between learner period characteristics and driving time to first crash and extended the model to include all crashes in the first year of independent driving. To account for changes in driving behavior after a crash,[30] we used a frailty model.[31]

Learner driving exposure (in hours, miles, and days of driving) and driving-associated behavior (driving instruction, errors, roadway variety, and KRD rates) that were collected during the learner period were included as independent variables. Survey measures assessed at baseline were also included. For hazard ratios (HRs) to be directly comparable,

units of measurement were standardized to the interquartile range.[32,33] Original data prior to standardization were also analyzed for comparison. Property damage crashes and police-reportable crashes were included as outcomes, while low-severity crashes (eg, tire strikes) were excluded.

Using the results from the univariate model, only variables with *P* values less than .10 were selected for the multivariable model and checked when the variance inflation factor was less than 10.[34] Best subsets were used to select the optimal combination of independent variables for multivariable models. For the final models, we used the bayesian information criterion and verified the proportional hazards assumption was met by checking the Schoenfeld residuals. There was no marked collinearity: the variance inflation factor was less than 1.10. Missing data for any variable accounted for less than 8% of the total data. All analyses were conducted in R version 3.6.0 (R Foundation for Statistical Computing). Data were collected from January 2011 through August 2014 and analyzed from September 2016 to January 2019. The *P* value thresholds were all less than .05.

Results

Participant Retention

Of the 298 individuals who responded, 90 fulfilled the eligibility criteria. Of the 90 teenage drivers recruited for the study, 83 participants completed the learner period and advanced to independent licensure. A single participant remained on a learner's permit at age 18 years and was no longer eligible to participate, reducing the sample of eligible to 82 (of whom 75 were white [91%] and 44 were girls [54%]). Of the 7 participants who did not complete the learner period, 4 withdrew because of vehicle-associated issues (the teenager or parent was involved in a crash and did not want to reinstall instruments in the new vehicle, sold the instrumented car, or moved out of state), and 3 remained on their learner's permits.

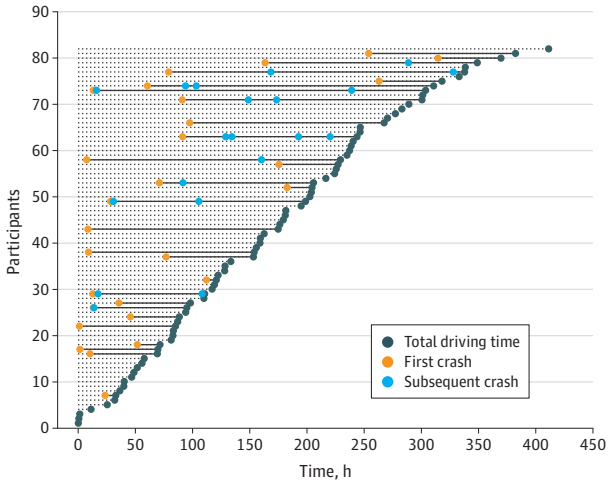
Learner Driving Experience and Crashes

The mean (SD) learner's permit duration was 10.35 (2.48) months. Teenagers drove a total of 18 686 trips, a mean (SD) of 207.6 (141.13) trips each. Driving occurred on a mean (SD) of 88.9 (45.6) days, for 1259.2 (939.7) miles, and 48.2 (33.3) hours. During the learner period, they were involved in 9 crashes in the instrumented vehicles. Additional details of the amount and variability of driving experience during the learner period are described in a previous report.[6]

Independent Driving Experience and Crashes

The mean (SD) independent license duration for participants in the study was 11.26 (2.93) months. During the independent driving period, teenagers drove a mean (SD) of 4637.60 (2880.36) miles, and 170.9 (97.0) hours, and 28 participants were involved in 49 property-damage or police-reportable crashes. Of these 28 participants with at least 1 crash, 11 accounted for an additional 21 property-damage or police-reportable-crashes (**Figure 1**). Univariate associations between the individual independent variables and driving time

Figure 1. Property-Damage Crashes or Police-Reportable Crashes During the First Year of Independent Licensure by Participant (N = 82)



to first crash and all crashes in the first year of independent driving are presented in **Figure 2** for both the original and standardized data. Descriptive statistics of these variables are listed in **Table 1**.

Driving Time to First Crash

Cox proportional hazard regression models were used to assess adjusted associations of the variables with the driving time to first crash. In a multivariable model of factors associated with driving time to first crash, the Schoenfeld residuals test was not significant, which is consistent with the proportional-hazards assumption. Results with original scales and after standardization are presented in **Table 2**. Standardized results are reported here.

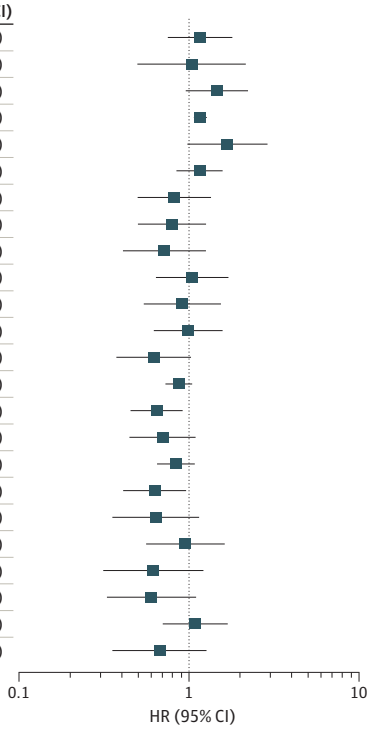
The sensation-seeking personality score (HR, 1.67 [95% CI, 1.08-2.57] per 0.75-unit increase) and KRD rates during the learner period (HR, 1.27 [95% CI, 1.12-1.43] per 9.24-unit increase) were positively associated with driving time to first crash. Performance errors during the initial learner period (during the first 10 hours of practice) were negatively associated with driving time to first crash during the first year of driving (HR, 0.44 [95% CI, 0.22-0.86] per increase of 6.48 errors).

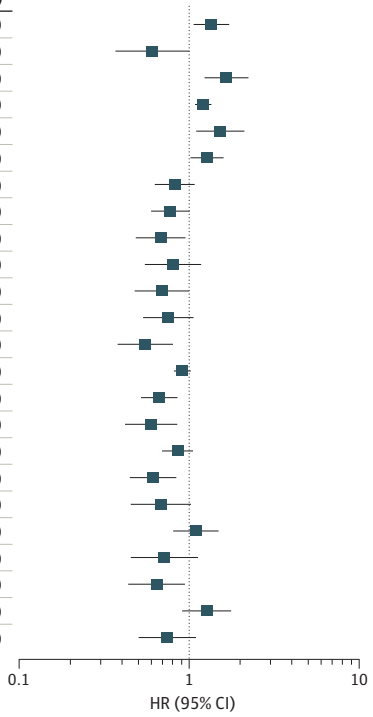
All Crashes in the First Year

Similar to the results for the first crash, the sensation-seeking personality score (HR, 1.66 [95% CI, 1.21-2.27] per 0.75-unit increase) and KRD rates during the learner period (HR, 1.19 [95% CI, 1.01-1.40] per 9.24-unit increase) were positively associated with all crashes in the first year. Performance errors during the initial learner period were also negatively associated with all crashes in the first year of independent driving (HR, 0.46 [95% CI, 0.28-0.76] per increase of 6.48 errors). The consistency of learner practice was negatively associated with all crashes in the first year (HR, 0.61 [95% CI, 0.38-0.99] per 0.23-unit increase). Although driving variety did not attain statistical significance when considered independently of the other covariates in the multivariable model (HR, 0.89 [95% CI, 0.58-137]), the inclusion of this variable improved model fit when

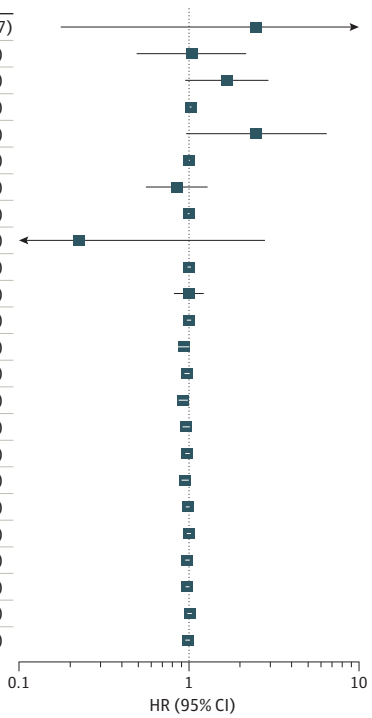
Figure 2. Standardized and Unstandardized Univariate Associations Between Individual Independent Variables and Driving Time to First Crash and All Crashes in the First Year

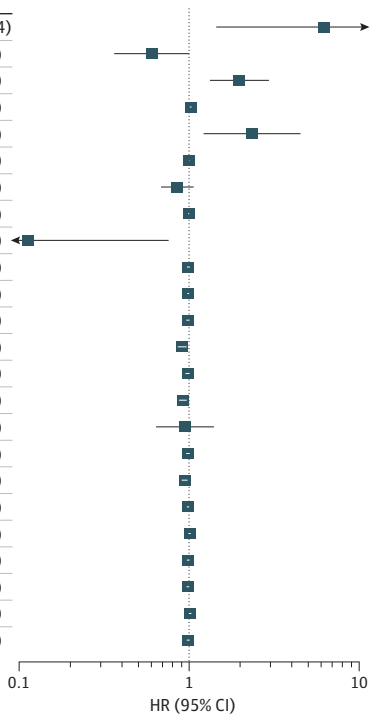
Variable	Driving time to first crash, HR (95% CI)	All crashes in the first year, HR (95% CI)
Age	1.16 (0.75-1.81)	1.36 (1.06-1.73)
Sex	1.04 (0.49-2.17)	0.60 (0.36-1.00)
Sensation-score seeking	1.46 (0.96-2.24)	1.67 (1.23-2.25)
KRD rate during LP	1.17 (1.07-1.27)	1.21 (1.08-1.35)
Risky friends	1.69 (0.98-2.92)	1.53 (1.10-2.13)
Days to licensure	1.15 (0.84-1.58)	1.28 (1.02-1.60)
Distance driven	0.82 (0.50-1.35)	0.82 (0.63-1.08)
Time driven	0.79 (0.50-1.26)	0.77 (0.59-1.01)
Driving consistency	0.71 (0.41-1.26)	0.68 (0.48-0.95)
Initial driving variety	1.04 (0.64-1.71)	0.80 (0.55-1.18)
Late driving variety	0.91 (0.54-1.55)	0.69 (0.48-1.00)
Total driving variety	0.99 (0.62-1.58)	0.75 (0.53-1.06)
Initial performance errors	0.62 (0.37-1.03)	0.55 (0.38-0.81)
Late performance errors	0.87 (0.72-1.04)	0.91 (0.81-1.02)
Total performance errors	0.64 (0.45-0.92)	0.66 (0.52-0.85)
Initial driving errors	0.70 (0.44-1.09)	0.60 (0.42-0.85)
Late driving errors	0.84 (0.65-1.08)	0.85 (0.69-1.05)
Total driving errors	0.63 (0.41-0.96)	0.61 (0.44-0.84)
Initial driving instruction	0.63 (0.35-1.15)	0.68 (0.45-1.03)
Late driving instruction	0.95 (0.56-1.63)	1.10 (0.80-1.49)
Total driving instruction	0.61 (0.31-1.22)	0.71 (0.45-1.13)
Initial functional instruction	0.60 (0.33-1.10)	0.64 (0.43-0.94)
Late functional instruction	1.09 (0.70-1.70)	1.27 (0.91-1.78)
Total functional instruction	0.67 (0.35-1.28)	0.74 (0.50-1.10)





Variable	Driving time to first crash unstandardized, HR (95% CI)	All crashes in the first year unstandardized, HR (95% CI)
Age	2.48 (0.18-34.87)	6.20 (1.44-26.64)
Sex	1.04 (0.49-2.17)	0.60 (0.36-1.00)
Sensation-score seeking	1.66 (0.94-2.93)	1.97 (1.32-2.94)
KRD rate during LP	1.02 (1.01-1.03)	1.02 (1.01-1.03)
Risky friends	2.49 (0.96-6.46)	2.34 (1.22-4.53)
Days to licensure	1.00 (1.00-1.01)	1.00 (1.00-1.01)
Distance driven	0.85 (0.59-1.29)	0.85 (0.68-1.06)
Time driven	0.99 (0.98-1.01)	0.99 (0.99-1.00)
Driving consistency	0.23 (0.02-2.79)	0.11 (0.02-0.76)
Initial driving variety	1.00 (0.98-1.03)	0.99 (0.97-1.01)
Late driving variety	1.00 (0.81-1.22)	0.99 (0.98-1.00)
Total driving variety	1.00 (0.97-1.03)	0.98 (0.96-1.00)
Initial performance errors	0.93 (0.86-1.00)	0.91 (0.85-0.97)
Late performance errors	0.97 (0.94-1.01)	0.98 (0.95-1.01)
Total performance errors	0.92 (0.87-0.98)	0.92 (0.87-0.97)
Initial driving errors	0.96 (0.91-1.01)	0.94 (0.64-1.00)
Late driving errors	0.98 (0.95-1.01)	0.98 (0.96-1.01)
Total driving errors	0.95 (0.90-1.00)	0.94 (0.90-0.98)
Initial driving instruction	0.98 (0.96-1.01)	0.98 (0.97-1.00)
Late driving instruction	1.00 (0.97-1.03)	1.00 (0.99-1.02)
Total driving instruction	0.98 (0.95-1.01)	0.99 (0.97-1.00)
Initial functional instruction	0.98 (0.95-1.00)	0.98 (0.96-1.00)
Late functional instruction	1.01 (0.98-1.04)	1.01 (0.99-1.03)
Total functional instruction	0.98 (0.95-1.01)	0.99 (0.97-1.00)





All distance driven, time driven, driving consistency, driving variety, performance errors, driving errors, driving instruction, and functional instruction variables were during the learner period (LP). KRD indicates kinematic risky driving.

Table 1. Descriptive Statistics of Learner Driving Experience and Factors Associated with Crashes During Independent Driving

Measure	Median	Unit increase[a] (range)
Age, y	15.58	0.17 (15.50-16.08)
Sensation-Seeking Personality Scale score	2.88	0.75 (1.38-4.75)
Risky Friends Scale score	2.20	0.31 (1.70-3.20)
Kinematic risky driving per 1000 mi while on learner's permit	3.97	9.24 (0-100.26)
Time on learner's permit, d	276	49.5 (264-665)
Learner's permit measures		
Distance driven, miles	1071.6	1198.8 (71.3-4963.5)
Time driven, h	40.57	38.07 (4.39-210.73)
Driving consistency[b]	0.28	0.23 (0.04-0.74)
Driving variety, No.		
Initial	32.32	20.75 (0.83-72.50)
Late	43.33	26.04 (0-81.94)
Total	36.67	16.03 (11.11-69.27)
Learner's permit performance errors, No.		
Initial	4.40	6.48 (0-34.17)
Late	1.89	5.22 (0-52.50)
Total	4.38	5.63 (0.42-32.50)
Learner's permit driving errors, No.		
Initial	10.23	9.21 (0-40.83)
Late	4.17	8.72 (0-55)
Total	7.72	8.75 (0.83-36.67)
Learner's permit driving instruction, No.		
Initial	61.53	23.87 (28.57-123.43)
Late	45.39	19.40 (21.54-100.00)
Total	56.59	22.29 (27.80-121.43)
Learner's permit functional instruction, No.		
Initial	56.64	23.74 (24.68-114.29)
Late	36.88	15.30 (18.46-85.42)
Total	47.22	20.24 (25.11-114.29)

[a] The unit increase for standardized hazard ratios is the interquartile range. The unit increase for original data is 1 for all covariates except learner permit distance driven, which is 1000 miles.

[b] Defined the number of days driven during the learner's permit period divided by the number of days the participants held their learner's permit.

considered jointly in the final model by bayesian information criteria.

Discussion

The learner period of GDL represents a unique opportunity to prepare teenagers to develop the skills and judgment necessary to keep them safe during independent driving.[7,35,36] Using continuous observation and intensive measurement of driving behavior, we tested the association between learner driver experience and driving time to first crash as well as all crashes in the first year of independent driving, an approach that is underused in crash-risk studies. We found that learner experience was associated with independent driving crash risk but was dependent on individual characteristics and the nature of the learner driving experience.

Consistent with a number of previous studies, a sensation-seeking personality was associated with elevated crash risk.[37,38] While an individual's sensation seeking is a psychological trait consistent with risk-taking,[39] parents could counter this propensity by closely supervising their teenager during independent driving. Parent-teen driving agreements that provide conditional access to a vehicle[28] are a proven measure that reduce crash risk.

Kinematic risky driving, or the abrupt maneuvering of the vehicle, is known to be associated with crash risk among both teenagers with new licenses and drivers with experience.[20,40] These events are commonly the result of inattention, poor anticipation skills, and acceptance of risk or minimal margins of safety. The prospective association between learner driving KRD rates and crash risk during independent driving has not been previously described, to our knowledge. In our study, it appears that the presence of an adult supervisor during the learner period did not always deter teenagers from engaging in risky driving behaviors as measured by KRD, or possibly, some parents did not discourage them fully. While elevated KRD rates during the learner period may represent inexperience and poor vehicle management skills, they also may indicate a more aggressive driving style that continues during independent driving. In-vehicle monitoring technologies or smartphone applications that measure KRD and provide feedback to parents are typically used during independent driving.[27] The findings of this study suggest their use as a protective measure could be extended to the learner period, providing feedback about these events to both the teenagers and their parents who are supervising.

Teenagers who practiced steadily throughout the learner period had a lower likelihood of crashing during the first year of driving, a finding that is supported by theories of learning, where skills develop through distributed practice.[41] Performance errors, such as loss of vehicle control, were also protective for crashes during the first year of driving. Trial and error are essential parts of developing mental models where an individual can anticipate outcomes, particularly when it is coupled with feedback.[42] Provided that mistakes during the practice are not catastrophic, then driving errors may constitute learning events that reinforce safer driving.

Strengths

The prospective study design using direct observation generated a wide range of variables and allowed us to examine if the learner driving experience could improve teenage drivers' safety during the first year of independent driving. In addition, naturalistic driving data provide unprecedented richness of data associated with human behavior, including verification of crashes, which eliminates the underreporting of safety incidents.[43]

Limitations

Objective, prospective measurement of driving behavior is resource intensive, because it requires instrumenting participants' vehicles with sensors and collecting data over

Table 2. Cox Model of Factors Influencing Driving Time to First Crash and All Crashes in the First Year

Learner driving experience and individual-level factors	Hazard ratio (95% CI)				
	Driving time to first crash (n = 82)		All crashes in the first year (n = 82)		
	Original data	Standardized data[b]	Original data	Standardized data[b] interval	Per-unit increase[a]
Sensation-Seeking Personality Scale score	1.98 (1.12-3.51)	1.67 (1.08-2.57)	1.97 (1.29-2.99)	1.66 (1.21-2.27)	0.75
Kinematic risky driving rate per 1000 mi	1.03 (1.01-1.05)	1.27 (1.12-1.43)	1.02 (1.00-1.03)	1.19 (1.01-1.40)	9.24
While on learner's permit					
Initial No. of performance errors	0.88 (0.79-0.98)	0.44 (0.22-0.86)	0.88 (0.82-0.96)	0.46 (0.28-0.76)	6.48
Driving consistency[c]	NA	NA	0.07 (0.00-0.95)	0.61 (0.38-0.99)	0.23
Late driving variety	NA	NA	1.00 (0.98-1.01)	0.89 (0.58-1.37)	26.04

Abbreviation: NA, not applicable.

[a] The unit increase for standardized data. The unit increase for original data was 1 for all covariates in the adjusted model.

[b] Standardized to the interquartile range.

[c] Defined the number of days driven during the learner's permit period divided by the number of days the participants held their learner's permit.

prolonged periods and therefore necessitates smaller, regional samples of participants who may not be representative of the general driving population. While the presence of vehicle instrumentation could have influenced participant behavior, previous research suggests that this does not occur or the influence is short term.[44]

Conclusions

Future studies may consider the use of low-cost, multisensor platforms, such as smartphones, to measure driving behavior in high-risk populations. Smartphone penetration among teenagers in the United States is 95%,[45] and these devices can measure acceleration, braking, and track location. Associated technologies could be used to disable other smartphone functions to minimize the opportunity for distraction.[46,47] Teenage drivers' crash risk during the first year of independent driving is associated with the sensation-seeking personality of the individual, as well as learner driving experiences that parents could influence, including KRD rates, consistency of practice, and driving errors. If these findings are confirmed in larger experimental studies, GDL laws could require a certain frequency of practice. Physicians could encourage parents to monitor their teenager's KRD rates throughout the learner period using in-vehicle or smartphone-based technology.

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