Higher Crash and Near-Crash Rates in Teenaged Drivers With Lower Cortisol Response
An 18-Month Longitudinal, Naturalistic Study

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IMPORTANCE Road traffic crashes are one of the leading causes of injury and death among teenagers worldwide. Better understanding of the individual pathways to driving risk may lead to better-targeted intervention in this vulnerable group.

OBJECTIVE To examine the relationship between cortisol, a neurobiological marker of stress regulation linked to risky behavior, and driving risk.

DESIGN, SETTING, AND PARTICIPANTS The Naturalistic Teenage Driving Study was designed to continuously monitor the driving behavior of teenagers by instrumenting vehicles with kinematic sensors, cameras, and a global positioning system. During 2006-2008, a community sample of 42 newly licensed 16-year-old volunteer participants in the United States was recruited and driving behavior monitored. It was hypothesized in teenagers that higher cortisol response to stress is associated with (1) lower crash and near-crash (CNC) rates during their first 18 months of licensure and (2) faster reduction in CNC rates over time.

MAIN OUTCOMES AND MEASURES Participants’ cortisol response during a stress-inducing task was assessed at baseline, followed by measurement of their involvement in CNCs and driving exposure during their first 18 months of licensure. Mixed-effect Poisson longitudinal regression models were used to examine the association between baseline cortisol response and CNC rates during the follow-up period.

RESULTS Participants with a higher baseline cortisol response had lower CNC rates during the follow-up period (exponential of the regression coefficient, 0.93; 95% CI, 0.88-0.98) and faster decrease in CNC rates over time (exponential of the regression coefficient, 0.98; 95%, CI, 0.96-0.99).

CONCLUSIONS AND RELEVANCE Cortisol is a neurobiological marker associated with teenaged-driving risk. As in other problem-behavior fields, identification of an objective marker of teenaged-driving risk promises the development of more personalized intervention approaches.
he World Health Organization has signaled that road traffic crashes are one of the leading causes of death worldwide in individuals 15 to 29 years of age. The first months of licensing are a particularly dangerous time. Strategies addressing contextual risk factors (eg, graduated driver licensing programs) aimed at all teenaged drivers are now in place in many states and countries. Nevertheless, persistently high crash rates in this age group suggest that certain subgroups remain at high risk and more individualized interventions are needed.

Investigation into individual risk factors for crashes among young drivers has centered primarily on demographic (eg, sex) and personality characteristics (eg, sensation seeking). To date, this research has not disentangled the marked heterogeneity of this population. As in other problem-behavior fields, the inability to discern high-risk endophenotypes whose members share a specific pathway and their objective markers represents a major obstacle to the development of individualized interventions capable of targeting those pathways.\(^7\)

Recent research points to a significant role for neurobiological processes in risky behavior, with stress regulation being one such potential process. The presence of a physical or psychological stressor normally results in a neuroendocrine response. One of these responses involves activation of the hypothalamic-pituitary-adrenal axis. Corticotrophin-releasing hormone, adrenal corticotropic hormone, and cortisol are the main hormones of the hypothalamic-pituitary-adrenal axis. Cortisol, which is secreted following increased synthesis and release of adrenal corticotropic hormone in response to increased release of corticotrophin-releasing hormone, is a frequently used peripheral marker of hypothalamic-pituitary-adrenal-axis activity.

The relationship between disruptive and/or asocial risky behavior and cortisol has been studied in different populations and age groups. In the adult population, relationships have been found in criminal offenders. Our research group extended these findings to the traffic-injury field by linking reduced cortisol response to stress to more severe and intracetable impaired driving behavior in adults.\(^14,15\)

However, in young people, investigations into the link between cortisol measures and disruptive, externalizing, or asocial risky behavior have yielded equivocal results. Some studies have shown the expected inverse relationship, while others have not. A meta-analysis by Alink and colleagues examined the relationship between externalizing behavior and either basal or response measures of cortisol. The results indicated a weak relationship between externalizing behavior and basal cortisol, which was higher for elementary school children than preschoolers, but no significant relationships in adolescents. Between-study differences in cortisol measurement, methods, and sampling may be contributing to the varied findings. At the same time, most studies in the Alink et al meta-analysis used cross-sectional designs with a single-point prevalence estimate of self-reported behaviors, a less than ideal approach for studying the dynamic nature of risky behavior. Aside from a few notable exceptions, to our knowledge, longitudinal studies that observe cortisol response and objective measures of risky behavior over significant periods of time are rare.

Technological advances in the traffic-related injury-prevention field overcome some of the conceptual and methodological shortcomings hampering research into mechanisms of driving risk. In-vehicle cameras and sensors permit continuous observation of driving with unprecedented acuity and ecological validity. Here, we used this technology in a cohort of newly licensed teenaged drivers to examine the association between cortisol response during a stress-inducing task measured at baseline and crashes and near crashes (CNCs) observed over a subsequent period of 18 months. We hypothesized that higher cortisol response is associated with (1) lower CNC rates and (2) a faster reduction in CNC rates over time.

Methods

This longitudinal, naturalistic study was conducted during the first 18 months of licensure of teenaged drivers. Its recruitment, inclusion and exclusion criteria, participant flow and attrition, methods, and compensation were facets of a larger study described in-depth elsewhere. \(^31\)

Recruitment and Selection Criteria of Participants

Newly licensed teenaged male and female drivers and 1 of their parents were recruited using flyers and newspaper advertisements and from driving schools from the Roanoke and Blacksburg areas in the Commonwealth of Virginia. At the time of the study, Virginia’s graduated driver licensing program allowed independent driving at age 16 years and 3 months with restrictions: no driving between midnight and 4 AM until age 18 years and no more than 1 minor-aged passenger for the first 12 months of independent driving, followed by a maximum of 3 minor-aged passengers until age 18 years (except siblings). A further restriction on cell phone use was implemented midway through the study. Participants had to be 16 years of age and have held a probationary driving license allowing independent driving for fewer than 3 weeks. Exclusion criteria included a diagnosis of attention-deficit/hyperactivity disorder, a condition associated with more frequent driving speed convictions and crashes, and ownership of a vehicle (eg, pick-up truck) with inadequate space for instrumentation. The institutional review board of the Virginia Tech Transportation Institute approved the study protocol. Parents provided written informed consent for their participation and written permission for the participation of their children; teenagers provided their written assent. Teenaged participants were compensated up to about $2000 for participation in all facets of the larger study.

Cortisol Response

Mathematical Task

Cortisol response to stress was induced with mathematical tasks measured once at the beginning of the 18-month driving phase of the study. Participants completed five 60- to 120-second tasks and attempted to obtain the highest number of...
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Correct answers. They were informed that $60 would be awarded to the individual who achieved the highest total score among a group of 10 participants. A meta-analysis of studies that used similar cognitive tasks indicated their ability to reliably produce a cortisol response \( d = 0.20 \). \( ^{39} \)

Cortisol Measurement
Salivary cortisol was collected at 15-minute intervals using a Salivette sampling device (Sarstedt Inc). Participants had to hold a cotton swab under the tongue for a few seconds until saturated with saliva. Eight samples were collected: 3 samples during the resting period before the mathematical tasks and 5 samples after the tasks. Samples were refrigerated immediately and until assayed with the Amerlex Cortisol Radioimmunoassay kit (catalog number 8758401; Ortho Clinical Diagnostics Inc). The cortisol assay sensitivity was 0.1 μg/100 mL; the intra-assay coefficient, 4.3%; and the interassay coefficient, 7.7%. Missing data owing to insufficient saliva in swabs (ie, cases with <50% of total swabs) were replaced using SPSS multiple imputation with 5 iterations and sex and nonmissing cortisol values as predictors. Area under the curve with respect to increase (AUC\(_C\)), which evaluates change in cortisol levels over time from cortisol level at rest, was the primary measure of cortisol response. Adding areas at each cortisol sample calculated an overall AUC\(_C\) score. \( ^{40} \)

Measurement of Driving Outcomes
Vehicle Equipment
The Virginia Tech Transportation Institute developed the vehicle instrumentation. A Linux-based computer continuously collected and stored vehicle network data from the OBD2 port as well as data from specific sensors installed for the study including 4 cameras for continuous video footage and validation of CNC events; an accelerometer box for longitudinal, lateral, and yaw kinematic information; and a global positioning system for vehicle position and mileage for objective measurement of driving exposure.

Exposure
Data coders opened each trip (ie, begins when ignition is on and ends when ignition is off) to identify the driver and accurately assign driving exposure (measured in kilometers) to participants. This step was necessary because some participants shared their vehicles with others.

CNC Rates
Crashes and near crashes are considered a measure of driving risk, which could be owing to several factors alone or in combination including the propensity for risky behavior, lack of experience, and inattention. In a previous study, we defined a crash as contact with a moving or fixed object (eg, other vehicles and objects on or off the roadway) at speeds in which kinetic energy is measurably transferred or dissipated. \( ^{35} \) We defined a near crash (or close call) as a circumstance requiring a rapid, evasive maneuver to avoid a crash, operationalized as braking, accelerating, steering, or any combination of control inputs approaching the vehicle’s limits. \( ^{35} \) A previous study showed that near crashes have similar precipitating character-

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Clarity and conciseness: 4

Accuracy: 4

Relevance: 4

Logical organization: 4

Overall quality: 4

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Table. Mixed-Effect Poisson Models for Crashes and Near Crashes and Cortisol Response

<table>
<thead>
<tr>
<th>Variable</th>
<th>Main Effect Model</th>
<th>Interaction Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>exp(β) (95% CI)</td>
<td>P Value</td>
</tr>
<tr>
<td>Intercept</td>
<td>0.71 (0.46-1.08)</td>
<td>.11</td>
</tr>
<tr>
<td>Time since licensure (3-mo clusters)</td>
<td>0.92 (0.82-1.02)</td>
<td>.12</td>
</tr>
<tr>
<td>AUCI</td>
<td>0.93 (0.88-0.98)</td>
<td>.007</td>
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<tr>
<td>Time × AUCI</td>
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<td></td>
</tr>
<tr>
<td>AIC</td>
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<td></td>
</tr>
</tbody>
</table>

Abbreviations: AIC, Akaike information criterion; AUCI, area under the curve as a function of increase for cortisol; exp(β), exponential of the regression coefficient.

Figure. Crash and Near-Crash Rate Change Over Time by High and Low Cortisol Response Groups

Results

General Description of the Sample

Forty-two young drivers were recruited. Data from 2 participants were not included in analyses; one participant had 4 missing cortisol samples (ie, 50%) and CNC frequency about 6 SDs above the mean, and the other had cortisol samples contaminated by blood. The remaining participants had 8 missing cortisol samples (insufficient saliva in swabs) distributed across 4 participants. Missing values represented 2.5% of the total number of cortisol samples and were replaced (see the Methods section). The final sample (N = 40; 19 males and 21 females) had a mean (SD) age of 16.45 (0.23) years. Sixty percent of families had income equal to or higher than $100 000. During the 18-month study, participants drove 409 146.6 km (mean [SD], 10 228.64 [5016.75] km) during which they were involved in 233 CNC events (22 crashes and 211 near crashes; mean [SD], 5.83 [4.79]).

Cortisol Response and CNC Rates

The mean (SD) cortisol AUCI was −1.23 (3.85) μg/100 mL. Correlational analysis indicated that cortisol AUCI was significantly related to overall CNC rate (r = −0.39, P < .05). Results of the main and interaction mixed-effect Poisson regression models are summarized in the Table. For the main effect model, the exponential of the regression coefficient for cortisol AUCI, which represents the CNC rate ratio between 2 groups with 1 unit difference in AUCI, was significantly smaller than 1 (0.93; 95% CI, 0.88-0.98). It indicates that drivers with higher AUCI values had significantly lower CNC rates. For the interaction model, the exponential of the regression coefficient for the time and AUCI interaction was significantly smaller than 1 (0.98; 95% CI, 0.96-0.99), indicating that the decrease of CNC rate over time was faster for drivers with higher AUCI. Sex was not significant when entered as a covariate in the model, and it did not significantly affect the estimation of other factors. Finally, for the interaction model, the exponential of the regression coefficient for time since licensure was smaller than 1, indicating an overall decrease in CNC rate over time and replicating results from previous analyses. The 2 alternative models focused on different aspects of CNC rate variation. A comparison was conducted to evaluate which model fitted the data better; the interaction model had a smaller Akaike information criterion value, which suggests a better fit of the data than the main effect model.

Analyses of the main and interaction mixed-effect Poisson regression models were conducted on each of the 40 longitudinal trajectories. However, the depiction of the relationships between these individual trajectories and cortisol AUCI is difficult to comprehend. Thus, the Figure provides a simplified representation of the longitudinal trajectory of the mean CNC rates over the 18-month period and after categorizing participants into either high or low cortisol AUCI groups using the K mean cluster method. The plots are consistent with the results of the Poisson models: drivers with higher cortisol values had lower overall CNC rates and faster reductions in CNC rates over time.

Discussion

The current study examined, in teened drivers, the relationship between cortisol response, measured at baseline, and CNC rates measured subsequently over the first 18 months of licensure. In general, novice teened drivers have high crash rates early in licensure that decline rapidly for about 6 months and 1500 km of driving and then more slowly for a period of years before reaching the level of experienced adult drivers. A reduction in CNC rates over time was found in this and previous analyses. Nevertheless, the average reduction in crash rates over time may not necessarily equate to equivalent reductions for all novice drivers. In this cohort, CNC rates among some drivers were found to be higher throughout or initially high with reduction over time. The results supported both our hypotheses concerning the association between cortisol response to stress and CNC rates in teened drivers. Teened drivers with higher cortisol response measured at baseline exhibited both lower overall CNC rates and faster decrease in CNC.
rates over time than those with lower cortisol response. These results held after accounting for sex, suggesting it had no moderating role. Future studies could examine other potential moderation and mediation effects in larger samples.

To our knowledge, this is the first study to examine the relationship between cortisol response and driving risk objectively and continuously measured over several months. Low cortisol response has been linked to risky behaviors, such as alcohol abuse, aggressive and asocial behavior, and treatment refractoriness, although the precise mechanisms underlying this linkage remain speculative. Nevertheless, the possibility that cortisol demarcates a neurobiological underpinning of driving risk in some drivers provides a plausible explanation for the selective responsivity to general prevention strategies such as graduated driver licensing programs, media-delivered safety messages, and increased parental management; some teenagers benefit, others do not. Alternative risk-reduction strategies in young drivers with a neurobiological basis for their driving risk may be needed such as the use of in-vehicle technologies (e.g., high g-force detection systems technology). The preliminary findings presented here justify continued research into the neurobiological basis of driving risk, a pragmatic context in which teenagers and young adults are most vulnerable.

This study possessed some important strengths. In particular, sophisticated in-vehicle technology allowed visual identification of the driver, accurate measurement of exposure and CNC rates, and hence driving risk. Some potential weaknesses are also noteworthy. One was the finding of a negative mean cortisol AUCI value. We used a cognitive task as a psychological stressor that, based on a meta-analysis, is associated with a low but reliable increase in cortisol in adults. The Trier Social Stress Test has been associated with larger increases in cortisol response in adults as well as adolescents. Future research into cortisol and driving risk in young drivers could benefit from use of this task to elicit heightened cortisol responding. Concerning generalizability of driving exposure, this sample’s similarity to national norms is difficult to appraise. Data sources, such as the National Household Travel Survey, may provide imprecise estimates of total exposure in this age group, while studies comparing exposure via self-report vs instrumentation find the former inflated. Participants also came from relatively high-income families. Their crash events, which represented about 10% of all CNCs, were minor and none resulted in serious injury. Thus, results may not generalize to other populations with significantly different characteristics or to crashes resulting in serious injury or death. Finally, naturalistic driving studies are expensive and therefore usually involve small sample sizes and/or short follow-up periods. While the present sample was limited, the follow-up period was extensive and measurement intensive. Further development of more affordable technologies promises studies with larger samples of teenaged drivers and prolonged follow-up periods.

Conclusions

This study found that cortisol, a neurobiological marker, was associated with teenaged driving risk; teenagers with lower response to stress were at higher risk for CNCs. As in other problem-behavior fields, identification of an objective marker of a specific pathway to teenaged driving risk promises the development of more personalized intervention approaches.

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ARTICLE INFORMATION

Accepted for Publication: November 15, 2013.
Published Online: April 7, 2014.

Author Contributions: Drs Ouimet and Guo had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

Study concept and design: Ouimet, Brown, Klauer, Simons-Morton, Lee, Dingus.

Acquisition, analysis, or interpretation of data: All authors.


Critical revision of the manuscript for important intellectual content: All authors.

Statistical analysis: Guo, Fang.


Administrative, technical, or material support: Brown, Klauer, Simons-Morton, Lee, Gianoulakis, Dingus.


Conflict of Interest Disclosures: None reported.

Funding/Support: This research was supported by the Intramural Research Program of the National Institutes of Health (grant N01-HD-5-3405) and by the National Highway Traffic Safety Administration. Cortisol sampling kits and analyses were provided by the Douglas Hospital Research Centre. Dr Ouimet was supported through a career grant from the Quebec Health Research Fund (Fonds de recherche du Quebec-Sante).

Role of the Sponsor: The funders had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

Additional Contributions: We thank the following persons for their help: Jennifer Mullen, AAS candidate, Virginia Tech Transportation Institute (VTTI), for project management and data collection; Julie McClafferty, MSc, VTTI, for management of data coding; Allen Belisma, MSc, Eunice Kennedy Shriver National Institute of Child Health and Human Development (NICHD), for statistical programming; Sophie Couture, PhD, Douglas Hospital Research Centre, for help in the implementation of the cortisol protocol; Erik C. B. Olsen, PhD, NICHD, for collecting the cortisol samples; and Li Bai, MSc, Douglas Hospital Research Centre, for analysis of the cortisol samples. The people who provided help for this study were either employees or graduate or postdoctoral students of the listed agencies. As such, they received a salary/stipend for their assistance.

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