2014

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Original Publication Citation

Vorona, R. D., Szklo-Coxe, M., Lamichhane, R., Ware, J. C., McNallen, A., & Leszczyszyn, D. (2014). Adolescent crash rates and school start times in two central Virginia counties, 2009-2011: A follow-up study to a southeastern Virginia study, 2007-2008. *Journal of Clinical Sleep Medicine, 10*(11), 1169-1177. doi:10.5664/jcsm.4192

NEW RESEARCH

JCSM
Journal of Clinical Sleep Medicine

pii: jc-00129-14
http://dx.doi.org/10.5664/jcsm.4192

SCIENTIFIC INVESTIGATIONS

Adolescent Crash Rates and School Start Times in Two Central Virginia Counties, 2009-2011: A Follow-up Study to a Southeastern Virginia Study, 2007-2008

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Background and Objective: Early high school start times (EHSST) may lead to sleep loss in adolescents ("teens"), thus resulting in higher crash rates. (Vorona et al., 2011). In this study, we examined two other adjacent Virginia counties for the two years subsequent to the above-mentioned study. We again hypothesized that teens from jurisdictions with EHSST (versus later) experience higher crash rates.

Methods: Virginia Department of Motor Vehicles supplied de-identified aggregate data on weekday crashes and time-of-day for 16-18 year old (teen) and adult drivers for school years 2009-2010 and 2010-2011 in Henrico and Chesterfield Counties (HC and CC, respectively). Teen crash rates for counties with early (CC) versus later (HC) school start-times were compared using two-sample Z-tests and these compared to adult crash rates using pair-wise tests.

Results: Chesterfield teens manifested a statistically higher crash rate of 48.8/1,000 licensed drivers versus Henrico's 37.9/1,000 (p = 0.04) for 2009-2010. For 2010-2011, CC 16-17 year old teens demonstrated a statistically significant higher crash rate (53.2/1,000 versus 42.0/1,000), while for 16-18 teens a similar trend was found, albeit nonsignificant (p = 0.09). Crash peaks occurred 1 hour earlier in the morning and 2 hours earlier in the afternoon in Chesterfield, consistent with commute times. Post hoc analyses found significantly more run-off road crashes to the right (potentially sleep-related) in Chesterfield teens. Adult crash rates and traffic congestion did not differ between counties.

Conclusions: Higher teen crash rates occurred in jurisdictions with EHSST, as in our prior study. This study contributes to and extends existing data on preventable teen crashes and high school start times.

Keywords: crash rates, start times, high school, teens

Citation: Vorona RD, Szklo-Coxe M, Lamichhane R, Ware JC, McNallen A, Leszczyszyn D. Adolescent crash rates and school start times in two central Virginia counties, 2009-2011: a follow-up study to a southeastern Virginia study, 2007-2008. *J Clin Sleep Med* 2014;10(11):1169-1177.

Most adolescents do not achieve the recommended 9 plus hours of sleep.[1,2] A study based on the Youth Risk Behavior Survey of US high school students found that a mere 8% obtained ≥ 9 hours on a school night.[3] Studies have demonstrated numerous, varied consequences of insufficient sleep in adolescents, including behavioral and cognitive abnormalities (e.g., risk taking and greater impulsivity),[4-7] mood decrements,[8,9] and impairments in academic performance[10,11] and driving.[12] Adolescents may achieve insufficient sleep for numerous reasons, such as technology use at bedtime and work schedules.[13,14] Research suggests early high school start times could be an etiology for sleep deprivation in adolescents.[15] Studies also suggest that adolescents demonstrate a circadian phase delay.[16-18] A key determinant of adolescent wake up times in those aged 15 to 17 has been shown to be school start times.[19] Thus, early high school start times might lead to both chronically restricted sleep (with increased sleep pressure[16]) and to misalignment of sleep/wake and circadian cycles. These alterations could degrade the performance of activities such as driving and academics, particularly during times of circadian troughs in alertness.[20]

BRIEF SUMMARY

Current Knowledge/Study Rationale: Our previous study of adolescent motor vehicle crash rates in two adjacent, demographically similar Southeastern Virginia cities with markedly different high school start times revealed that the city with earlier start times demonstrated a significantly higher adolescent crash rate for both years 2007 and 2008. Given the need for further research in this field, and to ascertain if previous findings would be replicated, we investigated, in another naturalistic study covering two school years (2009-2010, 2010-2011), whether adolescent crashes in two adjacent, demographically similar Central Virginia counties with distinctly different high school start times would differ, with higher crash rates hypothesized for the county with earlier start times.

Study Impact: Higher teen crash rates occurred in the Central Virginia county with early high school start times, thus not only replicating our earlier work, but also if both studies are considered, demonstrating increased teen crash rates in jurisdictions with earlier starting school systems for four consecutive years. This study adds to existing and emerging work supporting consideration for later high school start times and hopefully contributes to our understanding of preventable motor vehicle crashes in this susceptible population.

Insufficient sleep increases the risk of crashes in younger drivers.[12] Sleepy crashes are common in the United States, and

adolescents are likely to be an especially at-risk population. One study revealed that 7% of all crashes were drowsy crashes and that 16.5% of fatal crashes involved drowsy drivers.[21] Younger adults aged 16-24 years were most apt to be involved in drowsy crashes.[21] Another study revealed that 55% of sleepy crashes occurred in those younger than 26 years.[22]

Only modest data exist concerning high school start times and adolescent ("teen") crashes. A Lexington, Kentucky, study demonstrated a 16.5% decline in teen crashes in the two years after delaying high school start times by one hour.[23] We recently reported on teen crash rates in two neighboring and demographically similar Southeastern Virginia cities (Chesapeake and Virginia Beach) with starkly different high school start times.[24] The city with the earlier high school start time (Virginia Beach) demonstrated higher teen crash rates for the two consecutive years examined.[24] These differences in crash rates in 2007 and 2008 were not seen in non-teenaged drivers in the two cities.

The presence of another region in Virginia with two demographically similar counties and adjacent public school systems with different high school start times presented a natural opportunity to replicate our earlier study. We again hypothesized that a greater teen motor vehicle crash rate would occur in the jurisdiction with earlier high school start times.

Henrico County and Chesterfield County are geographically adjacent and demographically similar counties in Central Virginia. In school years 2009-2010 and 2010-2011, their public high school start times differed markedly, with Henrico County beginning at 08:45 and Chesterfield County at 07:20. The schools ended at 15:45 (telephone call to Henrico Public Schools 1/31/2014) and 13:50 (telephone call, Chesterfield Public Schools 1/31/2014), respectively.

For 2009-2010, Henrico County had 13 public high schools, with 15,461 students,[25] and average distance to school of 5.3 miles (Email 12/05/2012 Director of Pupil Transportation Henrico County Schools). Chesterfield County (2009-2010) had 14 public high schools (including a special needs school) with 18,188 students (telephone call 4/4/2014 Community Relations Department Chesterfield County Public Schools), with an average distance to school of 6.1 miles (telephone call 4/4/2014 Director of Department of Pupil Transportation Chesterfield County Public Schools).

Per the US Census Bureau, as of 2012, Henrico County had 60% white and 30% black citizens, and Chesterfield County had 70% white and 23% black citizens.[26,27] The areas of square miles (as of 2010) in Henrico and Chesterfield Counties were 234 and 423, with (as of 2008) 1,279 and 1,800 centerline miles of road, respectively.[28,29] In 2010, the population was 306,912 in Henrico County and 316,236 in Chesterfield County. Of the populations, 23.6% and 25.0%, respectively, were less than 18 years old as of 2012. In 2008-2012, the per capita income was $33,343 in Henrico County and $32,527 in Chesterfield County and, in 2010, the population densities were 1,313 and 747 per square mile, respectively.

A study in two Central Virginia jurisdictions replicating and extending the Southeastern Virginia study could, if results were similar, help to confirm earlier conclusions. In addition, it might allow a degree of longitudinal assessment by examining the two school years 2009-2010 and 2010-2011 subsequent to our prior study's examination of the years 2007 and 2008.

METHODS

The Eastern Virginia Medical School Institutional Review Board (IRB), Virginia Commonwealth IRB, and Old Dominion University IRB declared this study to be non-human subjects and thus exempt from IRB review. De-identified aggregate data from Henrico County and Chesterfield County were obtained from the Virginia Division of Motor Vehicles (DMV) for male and female drivers aged 16, 17, and 18 years, termed "teen drivers," and for all other ages termed "adult" (> 18 years) drivers. The DMV further supplied data on Monday through Friday crashes for male and female drivers 16 through 18 years for the school years 2009-2010 and 2010-2011. We investigated 16- to 18-year-olds in order to be inclusive of all those in high school and to provide a more conservative estimate of the crash rates than would be obtained by exclusion of 18-year-olds. As in our previous study,[24] we obtained Monday through Friday crash data for adult drivers (> 18 years) for the 2 counties for the same 2 school years. Thus, these teen and adult crash data allowed us to calculate crash rates (and their 95% confidence intervals) for teens and adults, respectively, in the 2 jurisdictions for 2 consecutive school years and to compare the crash rates between the 2 counties.

Our main analyses focused on comparing teen crash rates, and, to better interpret any findings, we ascertained if the crash rates for adults (non-teens) differed between the two counties. Differences in crash rates between counties only in teens would suggest an issue peculiar to teens, e.g., early high school start times, whereas differences for adults might suggest a systemic issue.

Our primary analysis compared crash rates per 1,000 drivers for 16-18 year old teen drivers in Henrico County versus Chesterfield County for 2 consecutive school years: 2009-2010 and 2010-2011. We used crash rates per 1,000 drivers, as this is an established methodology,[23,30,31] and as we wished to use a similar methodology to our 2011 study.[24] September through the end of May months defined the school year period. We evaluated 2010-2011 in addition to the 2009-2010 school year to determine if any differences found in crash rates would persist beyond one year and thus, be replicated. As we were specifically interested in the school year months, we used 2009 Department of Motor Vehicle (DMV) driver totals for months September through December and 2010 DMV driver totals for the months January through May as a best approximation for 2009-2010. Similarly, for 2010-2011, we used 2010 DMV driver totals for months September through December 2010 and 2011 DMV driver totals for the months January through May.

We also conducted the following secondary analyses. We evaluated crash data limited to 16- and 17-year-old drivers in both counties as a sensitivity/confirmatory analysis for our primary analyses of 16- to 18-year-old drivers. We thus compared crash rates per 1,000 drivers for 16-17 year old drivers in Henrico County vs. Chesterfield County. For these analyses, drivers aged 18 and older were considered adults or non-teen drivers.

The formulas used to calculate crash rates per 1,000 licensed drivers for each school year for adolescents aged 16-18, adolescents aged 16-17, as well as for adults (either > 18 or > 17 years) were as follows:

$$\text{Crash rate for September 2009–May 2010} = \left(\frac{\text{Total crash between Sept.–Dec. 2009}}{\text{Total licensed drivers in 2009}} + \frac{\text{Total crash between Jan.–May 2010}}{\text{Total licensed drivers in 2010}} \right) \times 1{,}000$$

$$\text{Crash rate for September 2010–May 2011} = \left(\frac{\text{Total crash between Sept.–Dec. 2010}}{\text{Total licensed drivers in 2010}} + \frac{\text{Total crash between Jan.–May 2011}}{\text{Total licensed drivers in 2011}} \right) \times 1{,}000$$

Our statistical analyses were as follows. To compare the difference in teenage (16- to 18-year-old) school year crash rates for 2009-2010 and 2010-2011 between Chesterfield County and Henrico County, we used a 2-sample Z-test, with $p \leq 0.05$ considered statistically significant. Ninety-five percent confidence intervals were also estimated for this difference in rate proportions. Male and female school year crash rates were also compared for teens between the counties using a 2-sample Z-test. The difference in crash rates (between Chesterfield County and Henrico County) for 16- to 18-year-olds was also compared to the difference in crash rate for adults (> 18 years) for both school years 2009-2010 and 2010-2011 using a paired t-test. Ninety five percent confidence intervals were estimated for these differences.

As secondary analyses, we conducted the same statistical analyses as above, but limited the analyses to 16- and 17-year-old drivers for school years 2009-2010 and 2010-2011. Combined, as well as male and female school year crash rates between 16-17 year old teens, were compared between the counties using the 2-sample Z test, and teens to adults between counties compared using a paired t-test. For these confirmatory analyses, adults (all other ages) were defined as those > 17 years old.

As ancillary analyses, teen crash rates (for drivers aged 16-18 years and 16-17 years) during 1-h periods of day were also compared between Henrico County and Chesterfield County for school years 2009-2010 and 2010-2011 using 2-sample Z-tests based on a normal approximation to test for statistical significance. This additional analysis of pre-school start and post-school dismissal helped to determine the reliability of the earlier findings.[24]

Additional ancillary results are provided in the supplemental material and include the following: time of day crashes superimposing present findings with prior work,[24] and monthly crash rates for teens aged 16-18 and adults > 17 years old.

We also compared levels of traffic congestion (uncongested, moderate congestion, and severe congestion) between Henrico County and Chesterfield County to determine whether these would vary and explain any differences in crash rates between the 2 counties. For comparing the 2 counties for traffic congestion, the 2-sample Z test for proportions was used. The Urban Transportation-MPO Division of the Richmond Regional Planning District Commission provided information on traffic conditions in Henrico County and Chesterfield County (http://www.richmondregional.org/About_Us/about_us.htm; 2/7/2014). They supplied data on Levels of Service for non-local roads in both Henrico County and Chesterfield County.

We also conducted post hoc secondary (supplemental) analyses on causes of crash for 16-18 year olds in Henrico County and Chesterfield County for the combined years 2009 and 2010. These data were obtained from the Virginia Department of Motor Vehicles Police Crash Report. The following causes of crashes were compared between the jurisdictions: apparently being sleep, driving fatigued, driving while drinking, and right and left run-off road crashes. We posited that the county with the greater overall crash rate for teens would also have higher crash event rates of run-off road crashes and sleepiness/fatigued. Run-off road crashes may result from driver sleepiness.[21] These 2-year cause-specific event rates (**Table S1**, supplemental material) were calculated by combining the causes of specific crashes (numerator) for years 2009-2010 (due to small numbers) and dividing by the average number of licensed drivers per year (as these overlap). A two-sample Z test for proportions was used to test the significance of results between the 2 counties.

RESULTS

Henrico County had a total of 8,560, 8,805, and 8,357 teenaged (16-18 years old) drivers for the years 2009, 2010, and 2011, respectively. Chesterfield County had 10,434, 11,059, and 10,275 teenaged (16-18 years old) drivers for the years 2009, 2010, and 2011, respectively. For school year 2009-2010, the total teen crashes for drivers aged 16-18 years in Henrico County and Chesterfield County were 329 and 524, respectively. In 2010-2011, 16-18 year old drivers in Henrico County and Chesterfield County had 378 and 550 crashes, respectively. **Table S1** demonstrates the number of male and female licensed drivers in Henrico County and Chesterfield County for ages 16, 17, and 18 and for all other ages in years 2009, 2010, and 2011.

Table 1 provides the crash rates per 1,000 for 16-18 year old male and female teens and 16-17 year old male and female teens in each jurisdiction for the 2 school years. For school year 2009-2010, 16-18 year old teens in the earlier starting Chesterfield County had a statistically significant increase in crash rates ($p = 0.04$). Female teens from Chesterfield County had significantly higher ($p = 0.04$) crash rates, while in males ($p = 0.09$), they were in the expected direction, though not statistically significant. Crash rates for teens aged 16-17 years again reveal the same statistically significant increase for Chesterfield County ($p = 0.04$) relative to Henrico County. For school year 2010-2011, there was a non-statistically significant ($p = 0.09$) trend towards more crashes in 16-18 year old drivers in Chesterfield County. For the same school year, females in Chesterfield County (but not males) had a statistically significant increase in crash rates over Henrico County ($p = 0.03$). Findings showed a similar pattern when limited to 16-17 year old drivers. Also, for school year 2010-2011, there was a statistically significant difference in crash rates for 16-17 year old drivers between the counties, with Chesterfield teens involved again in more crashes ($p = 0.05$). For this same year (2010-2011), the 16-17 year old females again appeared to manifest a statistically significant difference in crash rates between jurisdictions ($p = 0.01$), while the rate for males was not statistically significant.

Table 1—Average crash rates for adolescents ("Teens") 16–18 years and 16–17 years in Chesterfield and Henrico Counties for school years 2009–2010 and 2010–2011.

		Average School-Year Crash Rates/1,000 Licensed Drivers				
Year	Age/Group	Chesterfield	Henrico	Difference in Rates* (Chesterfield − Henrico)	p-value	95% CI of difference
Sept. 2009–May 2010	Teen (16–18 years)	48.8	37.9	10.9	0.035	0.8, 20.9
	male	49.0	37.8	11.2	0.089	-1.9, 24.4
	female	48.5	37.7	10.8	0.042	0.5, 21.2
	Teen (16–17 years)	46.9	35.5	11.5	0.044	0.4, 22.6
	male	50.2	34.3	16.0	0.051	-0.1, 32
	female	43.8	36.6	7.3	0.291	-6.8, 21.5
Sept. 2010–May 2011	Teen (16–18 years)	51.9	44.2	7.7	0.088	-1.3, 16.8
	male	49.1	45.5	3.7	0.361	-6.7, 17.4
	female	52.8	41.2	11.6	0.025	1.7, 21.6
	Teen (16–17 years)	53.2	42.0	11.2	0.046	0.2, 22.1
	male	51.9	44.9	7.0	0.323	-7.6, 21.6
	female	54.0	37.9	16.1	0.010	4.5, 27.8

CI, confidence interval. *Difference of average crash rates between the 2 counties may not be exact subtraction of Chesterfield − Henrico Crash Rates due to rounding. The maximum difference in reported value of difference from the exact difference due to rounding is ± 0.1.

Table 2—Average crash rate for adults (> 18 years) in Chesterfield and Henrico Counties for Sept. 2009–May 2010 and for Sept. 2010–May 2011.

		Average School-Year Crash Rates/1,000 Licensed Drivers				
Year	Group	Chesterfield	Henrico	Difference in Rates (Chesterfield − Henrico)	p-value	95% CI of difference
Sept. 2009–May 2010	Adult (> 18 years)	13.4	13.8	-0.4	0.608	-2.0,1.2
Sept. 2010–May 2011	Adult (> 18 years)	12.9	14.2	-1.3	0.284	-3.5,1.0

CI, confidence interval.

Table 3—Adult (> 18 years) and teen (16–18 years) crash rate comparison for Henrico and Chesterfield Counties for school years 2009–2010 and 2010–2011.

		Average School-Year Crash Rates/1,000 Licensed Drivers				
Year	County	Adult (> 18 years)	Teen (16–18 years)	Average Difference (Adult − Teen)	p-value	95% CI of difference
Sept. 2009–May 2010	Chesterfield	13.4	48.8	-35.4	< 0.001	-42.2, -28.6
Sept. 2010–May 2011		12.9	51.9	-39.0	< 0.001	-47.4, -30.6
Sept. 2009–May 2010	Henrico	13.8	37.9	-24.1	< 0.001	-32.6, -15.6
Sept. 2010–May 2011		14.2	44.2	-30.0	< 0.001	-35.9, -24.2

CI, confidence interval.

Table 2 shows the crash rates for adults > 18 years in Chesterfield County and Henrico County for the 2 school years. Unlike teen crash rates, there were no statistically significant differences in crash rates for either of the 2 years between the counties for adults. For 2009-2010 and 2010-2011, the adult crash rates for Henrico County were 13.8 and 14.2, respectively, and, for Chesterfield, they were 13.4 and 12.9.

In both counties, crash rates for teens relative to adults (> 18) were statistically significantly different ($p < 0.001$) for both school years (**Table 3**). In Chesterfield County, teens crashed 3.6 and 4.0 times as often as adults did for 2009-2010 and 2010-2011 school years, respectively. In Henrico County, teens crashed 2.7 and 3.1 times as often as adults for 2009-2010 and 2010-2011 school years, respectively.

Table 4 presents the same comparison as **Table 3** in that it compares crash rates for those aged 16-17 to those over 17 years of age for both counties. Again, teens displayed a much higher crash rate than did adults ($p < 0.001$), and this difference between teens and adults was more marked in Chesterfield County.

Table 5 compares the difference in school year crash rates between teens and adults in each of the jurisdictions. The difference between 16-18 year old teens and adults in Chesterfield County was statistically greater than the difference between 16-18 year old teens and adults in Henrico County ($p = 0.03$) for 2009-2010. For 2010-2011, this greater difference in Chesterfield County just misses achieving statistical significance ($p = 0.06$). The crash rate differences between 16-17 year

Table 4—Adult (> 17 years) and teen (16–17 years) crash rate comparison for both Henrico and Chesterfield Counties school years 2009–2010 and 2010–2011.

Year	County	Average School Year Crash Rates/1,000 Licensed Drivers		Average Difference* (Adult − Teen)	p-value	95% CI of difference
		Adult (> 17 years)	Teen (16–17 years)			
Sept. 2009–May 2010	Chesterfield	13.4	46.9	-33.6	< 0.001	-41.5, -25.7
Sept. 2010–May 2011		13.0	53.2	-40.2	< 0.001	-50.6, -29.9
Sept. 2009–May 2010	Henrico	13.7	35.5	-21.7	< 0.001	-30.7, -12.8
Sept. 2010–May 2011		14.1	42.0	-27.9	< 0.001	-35.0, -20.9

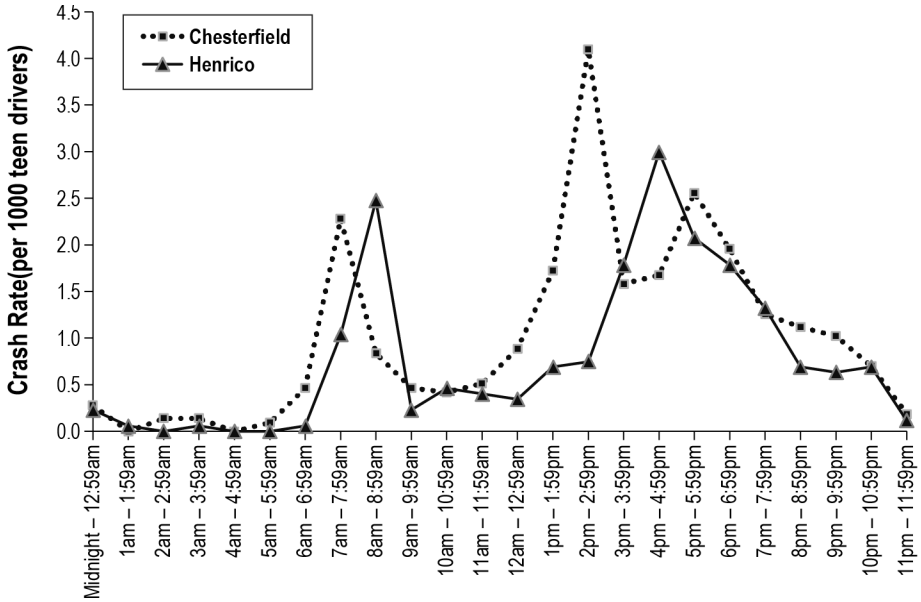
CI, confidence interval. * Difference of average crash rates between the 2 counties may not be exact subtraction of Chesterfield − Henrico Crash Rates due to rounding. The maximum difference in reported value of difference from the exact difference due to rounding is ± 0.1.

Table 5—Comparison of difference between teen versus adult crash rates in two counties for school years 2009–2010 and 2010–2011.

Difference group	Year	Difference in Teen vs. Adult Crash Rates/1,000 Licensed Drivers		Average of Differences	p-value	95% CI of difference
		Chesterfield	Henrico			
Teen (16–18) − Adult (> 18)	Sept. 2009–May 2010	35.4	24.1	11.3	0.03	1.3, 21.3
	Sept. 2010–May 2011	39.0	30.0	9.0	0.059	-0.4, 18.4
Teen (16–17) − Adult (> 17)	Sept. 2009–May 2010	33.6	21.7	11.8	0.036	0.9, 22.8
	Sept. 2010–May 2011	40.2	27.9	12.3	0.039	0.9, 23.8

CI, confidence interval.

Figure 1—Weekday crash rate of 16 to 18-year age groups in Chesterfield County and Henrico County for School Year 2009–2010 (Sept. 2009–May 2010).



old teens and adults in Chesterfield County were statistically greater than the differences between 16-17 year old teens and adults in Henrico County for both school years.

Figures 1 and **2** present time of day "morphology" for crashes for 16-18 year olds in Henrico County and Chesterfield County for the school years, 2009-2010 and 2010-2011, respectively. In each case, the peak for the early starting jurisdiction (Chesterfield County) began roughly an hour earlier in the morning (than Henrico County) and again approximately 2 hours earlier in the afternoon. **Figures S1** and **S2** (supplemental material) reveal a very similar pattern in time of crashes for 16-17 year old drivers as for 16-18 year olds for both school years.

Table S2 (supplemental material) gives hourly crash rate comparisons in tabular form for both school years. These data

Figure 2—Weekday crash rate of 16 to 18-year age groups in Chesterfield County and Henrico County for School Year 2010–2011 (Sept. 2010–May 2011).

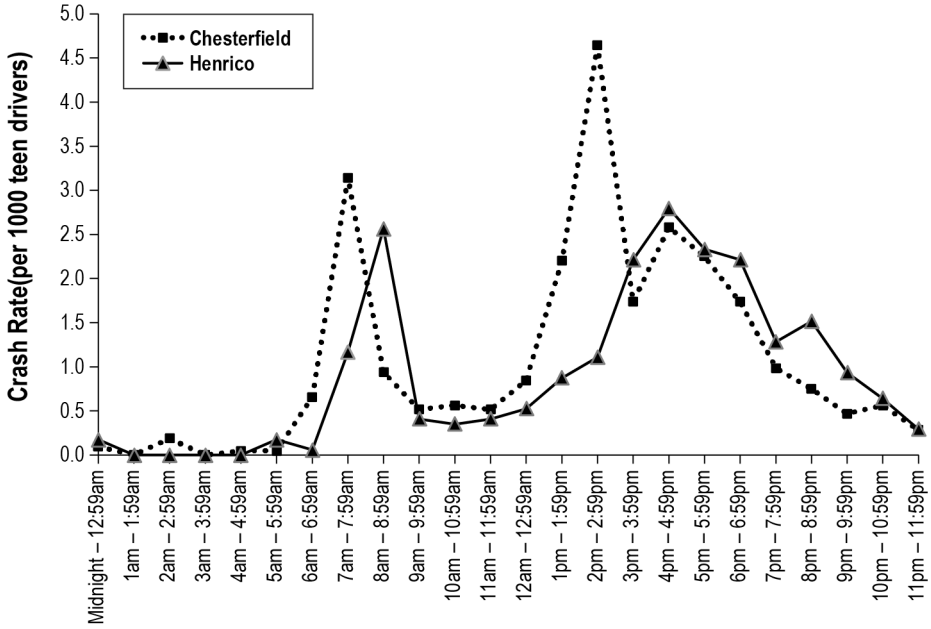


Table 6—Percentage of roads with traffic congestion in Chesterfield County and Henrico County.

Congestion	Chesterfield	Henrico	Difference	p-value
Uncongested	88.6%	87.2%	1.4%	0.562
Moderate congestion	9.4%	10.3%	-0.92	0.670
Severe congestion	2.0%	2.5%	-0.45	0.673

2009 data from Virginia Department of Transportation provided by Urban Transportation Planning Division, Richmond Regional Planning District Commission.

reveal that from 07:00 to 07:59 for both years, the crash rate was significantly higher ($p = 0.003$ and $p \leq 0.001$ for 2009-2010 and 2010-2011, respectively) in Chesterfield County than Henrico County. For 08:00 to 08:59, Henrico County had the significantly higher crash rate ($p < 0.001$) for both years. In the afternoon, Chesterfield County teens demonstrated a significantly higher crash rate from 13:00-13:59 for both school years ($p = 0.004$ and $p = 0.001$, respectively) and from 14:00 to 14:59 for both years ($p < 0.001$ for both school years). From 16:00 to 16:59, Henrico teens demonstrated the higher crash rate for each year, but these differences only reached statistical significance for the school year 2009-2010 ($p = 0.007$).

Figures S3 and **S4** (supplemental material) superimpose time of day crashes for this Central Virginia study from 2009-2011 on our previous work in Southeastern Virginia from 2007 and 2008. Crashes in counties/cities with the earlier starting schools are presented in **Figure S3**, and crashes in counties with the later schools shown in **Figure S4**. Similar patterns can be seen between 2009-2011 and 2007-2008 for crashes occurring in the earlier starting jurisdictions, and for the 2009-2011 and 2007-2008 for the later jurisdictions.

Figure S5 (supplemental material) presents monthly crash rates for 16-18 year old teens in Henrico County and Chesterfield County for both the 2009-2010 and 2010-2011 school years. **Figure S6** (supplemental material) reveals the same monthly crash rate data, but for adult drivers in Henrico County and Chesterfield County.

Table 6 compares Level of Service for non-local roads in Henrico County and Chesterfield County. There were no statistically significant differences between uncongested, moderately congested, and severely congested road conditions in the 2 counties. This suggests that congestion was not responsible for the differences in crash rates found in **Table 1**.

For our secondary post hoc analyses (**Table S3**, supplemental material), statistically significant differences between the counties for 2-year cause-specific crash rates were found for run-off road crashes to the right, with the higher rate for earlier starting Chesterfield County relative to Henrico County. While not statistically significant, similar trends were found for fatigue/fall asleep crashes and run-off road crashes to the left.

DISCUSSION

This study confirmed our hypothesis as teens from the county starting public high school 85 minutes earlier were involved in more crashes than teens from the county starting high school later. For 2009-2010, Chesterfield teens did indeed manifest a higher crash rate than the later starting Henrico teens. This occurred in 16-18 year old drivers and 16-17 year old drivers. For 2010-2011, we found that 16-17 year old Chesterfield teens also

had a statistically significantly higher crash rate than Henrico teens. In 2010-2011, 16-18 year Chesterfield teens demonstrated an overall trend towards more crashes. The difference was statistically significant in female teen drivers in Chesterfield County. There was no such difference in adult crash rates for either year in Henrico County and Chesterfield County, making it less likely that a systemic (not teen-specific) difference between the two counties was the etiology of these findings.

Our 2011 study comparing two Southeastern Virginia cities (for years 2007 and 2008) also demonstrated that the jurisdiction with the earlier public high school start time had a statistically significantly increased teen crash rate.[24] The methodology of both studies (e.g., using de-identified aggregate data) does not allow a causal relationship to be established between early high school start times and teen crashes. However, the findings suggest that early high school start times put teens at risk for sleep restriction and conflict with the phase delay that typifies adolescents' circadian rhythms. This study hopefully contributes to the emerging field of adolescent sleep health.

Just as with our previous study, we found increases in crashes during times that students would normally travel to and from school. The early morning commute spike could result, at least in part, from sleep inertia and circadian vulnerability.[20] Similarly, the spike in early afternoon crashes in Chesterfield County teens is likely secondary to the afternoon circadian dip in alertness.

This study has numerous strengths. The Virginia Department of Motor Vehicles data allowed us to examine crashes from all teen and adult drivers in each county. Both counties have relatively large populations, and they are demographically similar. The fact that they are adjacent geographically should mitigate concerns that weather conditions might have had an impact on the different crash rates. Sixteen- and 17-year-old drivers were also evaluated since some 18-year-olds may have graduated from high school and entered college or the workforce. Additionally, we analyzed two years of data, specifically the school year months and Monday through Friday data. In addition, present data, when added to prior Southeastern Virginia data, may suggest a longitudinal assessment. The data demonstrate consistently that from 2007-2011, teen crashes are higher in jurisdictions with earlier starting high school start times.

Another attribute of this study is that it is in many ways a replication study. Replication of scientific studies has been recommended to engender greater confidence in the veracity of the results.[32]

As post hoc secondary analyses (**Table S3**), we examined police crash records for causes of crashes and type of crashes among 16-18 year old teens in Henrico County and Chesterfield County. Chesterfield County adolescents had a statistically significantly higher rate of crashes than Henrico County due to run-off the road to the right. This finding may be a clue to more sleepiness occurring in these earlier high school-starting teens, as run-off road crashes have, as mentioned, been considered an indirect measure of sleepiness.[21] Driver fatigue status and driver inattention are among the factors that have been significantly associated with run-off road accidents. [33] While the other causes of crash findings examined were not found to be statistically significantly different between counties, higher numbers of crashes (and crash rates) attributable to run-off road to the left, to fatigue, and to sleepiness occurred in Chesterfield County than in Henrico County. The numbers of crashes ascribed by police to sleepiness and/or fatigue (or any other disturbance in condition or distraction) were few. The most common Driver Condition listed was "No Defects," and the most common Driver Distraction was "Not Applicable." In contrast to the very low numbers of crashes ascribed by police in Henrico County and Chesterfield County to sleepiness in this study, research has ascribed an estimated 7% of crashes to drowsiness,[21] with teens considered especially at risk.

These ancillary post hoc analyses of crash-specific rates were limited because we could not identify individuals with the specific exposure (e.g., fatigue) in the denominator and because the rates refer to events, not individuals with the event. Therefore, the same individual may have had more than one event. Irrespective of statistical significance, however, the observed differences in cause-specific events were consistent with those found for the overall crash rates. These secondary post hoc analyses may thus confirm the original findings.

This study has several limitations. As in our 2011 study, our primary limitation is that we were only able to obtain aggregate driving data from the DMV. Thus, we were unable to investigate individual-level factors that may have contributed to differences in crash rates between the jurisdictions. Examples could include work hours,[14] whether teens were involved in multiple crashes, engaged in risky behaviors, or had poor sleep habits. Furthermore, crash rate differences may have related to factors we were unable to assess such as crash type and vehicle type.[34]

Our analyses do not investigate crash rate per distance driven. Previous research has demonstrated that a greater likelihood of crashes is associated with more time spent driving.[35] Other studies have used vehicle miles traveled [36] and crash rate per unit distance,[37] and such data would be of interest. We present crash rates in terms of crashes per 1,000 licensed drivers for several reasons. As noted in the Methods section, crashes per number of drivers is an established approach[23,30,31] and one that we used (and wished to replicate) in our 2011 study.[24] Furthermore, Virginia Department of Motor Vehicles data on vehicle miles driven were not available, particularly for adolescents driving during the school year months on weekdays.

Beyond the lack of data, there are other potential difficulties with attempting to investigate differences between the two counties in crashes per distance driven. These include differences in number of high schools, distinct numbers of students and student drivers traversing different distances to high schools, and the probability some students attend schools across county lines or other zoned areas. Given that many roads are arterials rather than highways, determining distances traveled would likely require sophisticated technology such as Bluetooth tracking.[38]Even such a sophisticated measure would not differentiate between adolescent and adult drivers.

Chesterfield County did have a 15% but small (0.8 mile) average greater distance to school than Henrico County. We cannot unequivocally rule out that this contributed to the difference in teen crash rates. However, we are unaware of data that such modest differences in distance would translate to an important difference in crash rates. In fact, the relationship of distance driven and crash rate is not clear and may be nonlinear.[39]

In addition, Chesterfield County has an 81% greater square mile area than Henrico County, but only 41% more roads and

roughly an equivalent population. We cannot rule out that such differential ("sparser") conditions played a role in the greater teen crash rate in Chesterfield County. The similar Chesterfield and Henrico adult crash rates and congestion figures, however, likely argue against an important systemic difference between the counties. In addition, in our 2011 paper, it was Chesapeake with the larger square miles (than Virginia Beach) and lower population ("sparser") that had a lower crash rate.

We do not have data on crashes that were unreported to the Department of Motor Vehicles (e.g., unlicensed drivers). We have no reason to believe that there should be a systematic difference between Henrico County and Chesterfield County in the number of unreported crashes. One might also argue that the present data may not be generalizable to other jurisdictions, such as more rural and less populated areas.

We did not include crash rate data for summer months. While differences in crash rates between summer and the school year might be of interest, the potentially confounding variables in summer would likely preclude a clear interpretation of these data. Thus, we chose specifically to investigate school months because of the more regimented wake times and driving times that school dictates. In addition, we were concerned that, during summer, other variables would make interpretation of results difficult (e.g., vacations, car travel out of area, summer school, summer work, more irregularity in schedules, reduction in number of cars and buses on the road, and several major holidays).

For similar reasons, we considered but determined not to investigate crash data for weekend days. First, our focus was on weekdays when students must awaken and drive (at least for school purposes) at specified times. Secondly, we attempted to perform a study that followed up on our 2011 study.[24] Thirdly, we were concerned that other factors such as variable traffic patterns would render weekend analyses confounded.

Other limitations of our aggregate data include the lack of sleep quantity or quality measures. Both amount and quality of sleep may alter different types of adolescent functioning.[4,12,40] Such data could, for example, contribute to a better understanding of why female teens often exhibited the greater crash rate differences in Central Virginia.

Without data on weekday and weekend sleep, it is difficult to readily interpret the relationship of weekday versus weekend crash data. Discrepancies between weekend and weekday adolescent sleep, as measured in the literature by weekend sleep delay, weekend oversleep, and sleep duration differences have been associated with poorer school performance, depressed mood, and increases in risk-taking behaviors (including substance use).[5,6,41] The complexity of these data, with variable measures and some mixed findings, for example, regarding weekend oversleep[5,6] informed our decision to restrict our analysis to weekday data. While we recognize that alterations in these sleep habits might also negatively impact weekday (and weekend) teen driving, such an analysis is beyond the scope of this paper.

Furthermore, although we could have compared teen drivers to other more circumscribed adult age groups, we felt this to be beyond the scope of the study. Our purpose was to determine whether teen and non-teen crash rates in the two counties differed in order to draw conclusions regarding the teen crash rate. We did not investigate starting times of private high schools in Henrico County and Chesterfield County. However, a search for private schools specifically located in Henrico County demonstrated only one school of more than 1,500 students (kindergarten through 12th grade)[42] and that Chesterfield County had only one private school with more than 500 students (prekindergarten through 12th grade).[43]

One might postulate that students from the earlier starting Chesterfield County would have a greater crash rate secondary to lower levels of morning (drive time) environmental illumination. However, the monthly crash data and time of crash data for 16-18 year old teens may argue against this being a salient issue. First, the highest monthly crash rate found in Chesterfield County for either school year occurred in May 2011 when sunrise began at 06:15 am on May 1 and began at 05:51 by May 31 (http://wwp.greenwichmeantime.com/time-zone/rules/usa/). Secondly, although there was a spike in morning crash rates for both counties, the more remarkable peaks in teen crash rates occurred in the afternoon when lighting would not have been attenuated for the early finishing Chesterfield County students.

In our 2011 study from Southeastern Virginia, traffic congestion data did not support congestion as a possible arbiter of the differences in teen crash rates. Similarly, traffic congestion data from the Richmond Regional Planning District Commission re: Henrico County and Chesterfield County do not demonstrate differences that might explain our finding. Additionally, we note that the distance on average to high schools was very similar in Henrico County and Chesterfield County. Finally, U.S. Census Bureau data on the two counties revealed similar average commute times 2008-2012 with 22 minutes for Henrico County and 25 minutes for Chesterfield County. However, we cannot unequivocally exclude differential traffic conditions as a cause for more crashes amongst Chesterfield teens.

This study adds to the body of research that suggests that early high school start times may be disadvantageous for teen driving safety. As teens are a vulnerable population (e.g., much higher crash rate than adults in both Central Virginia and in in Southeastern Virginia),[24] this is an especially relevant issue. Within the Commonwealth of Virginia, we have now found two sets of adjacent, relatively large, and demographically similar jurisdictions where teens from jurisdictions with earlier starting public high schools manifest a higher crash rate. Our data for the present and past studies thus cover four consecutive years and two different regions of Virginia.

Recent work has demonstrated that delays in school start times may benefit teens in numerous ways. Even a 30-minute or a 25-minute delay in school start times increases sleep times and decreases sleepiness and mood difficulties.[44,45] Another study revealed improvements in attention with increased amounts of sleep.[46]Recently, Wahlstrom et al. noted (in a large study spanning three states) an association of later start times with increased sleep and with improvements in academics, mood, attendance, and car crashes.[47]

Some jurisdictions in the United States are currently considering starting high schools later. Changes to school schedules involve multiple stakeholders and are complex. We hope that these data aid those responsible as they consider the pros and cons of later high school start times. This study advances a small but important area of research investigating high school start times and preventable adolescent crash risks.

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ACKNOWLEDGMENTS

This work was performed at Eastern Virginia Medical School, Old Dominion University and Virginia Commonwealth University. The authors gratefully acknowledge the contributions of Ms. Lam Phan, Virginia Department of Motor Vehicles Data Manager, and her colleagues at the Virginia Department of Motor Vehicles, Ms. Tiffany Dubinsky, Senior Transportation Planner, and Ms. Greta Ryan, Senior Transportation Planner, both of the Urban Transportation-MPO Division of the Richmond Regional Planning District Commission and Dr. Robert Wingfield, Director of Pupil Transportation Chesterfield County, Virginia.

SUBMISSION & CORRESPONDENCE INFORMATION

Submitted for publication April, 2014
Submitted in final revised form July, 2014
Accepted for publication August, 2014
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DISCLOSURE STATEMENT

This was not an industry supported study. The authors have indicated no financial conflicts of interest.

SUPPLEMENTAL MATERIAL

Table S1—Number of licensed drivers in Chesterfield and Henrico Counties for years 2009, 2010, and 2011 by age and gender.

	Driving Groups by Age and Gender							
County	16 year old Males	16 year old Females	17 year old Males	17 year old Females	18 year old Males	18 year old Females	All Drivers > 18 years	All Drivers > 17 years
Chesterfield 2009	1,439	1,620	1,790	1,791	1,896	1,898	213,604	217,398
Chesterfield 2010	1,604	1,666	1,814	1,970	2,013	1,992	215,595	219,600
Chesterfield 2011	1,258	1,343	1,801	1,849	1,933	2,091	219,200	223,224
Henrico 2009	1,158	1,305	1,409	1,460	1,572	1,656	202,964	206,192
Henrico 2010	1,241	1,338	1,444	1,577	1,584	1,621	205,330	208,535
Henrico 2011	1,041	1,063	1,408	1,560	1,568	1,717	209,195	212,480

Data obtained from the Commonwealth of Virginia Department of Motor Vehicles.

Figure S1—Weekday crash rate of 16 to 17-year age groups in Chesterfield County and Henrico County for school year Sept. 2009–May 2010.

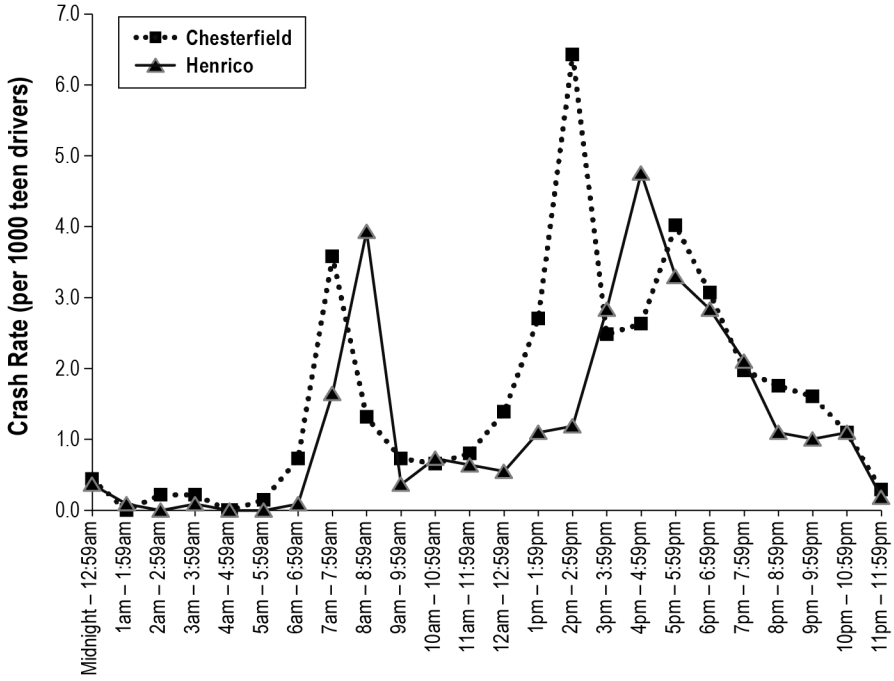

Figure S2—Weekday crash rate of 16 to 17-year age groups in Chesterfield and Henrico for school year Sept. 2010 – May 2011.

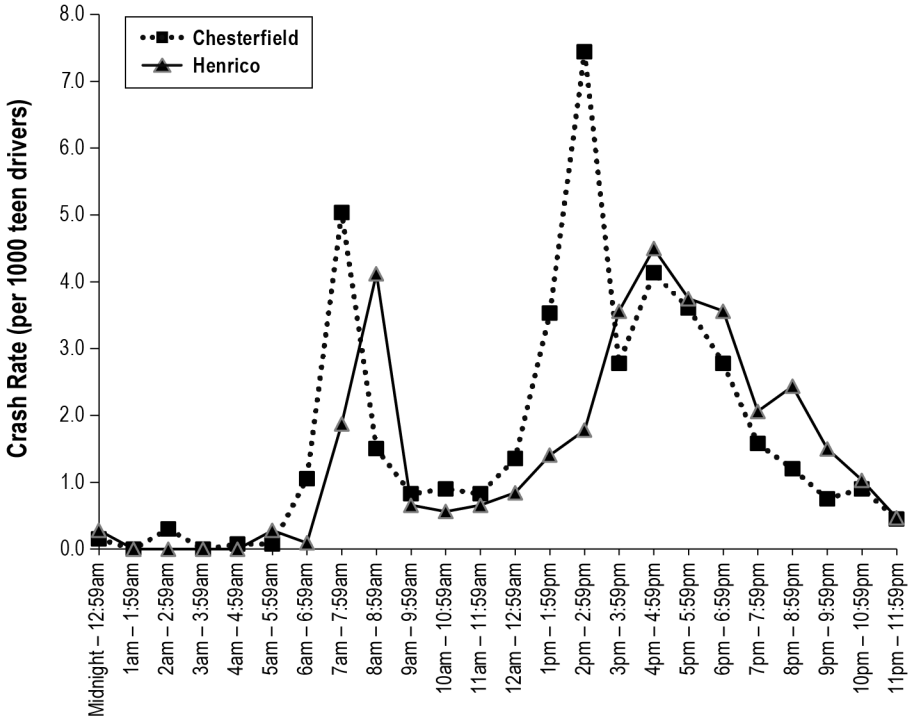

Table S2—Weekday crash rate of 16–18 year old age group in Chesterfield County and Henrico County for school years 2009–2010 (Sept. 2009–May 2011) and 2010–2011 (Sept. 2010–May 2011).

	Sept. 2009 – May 2010				Sept. 2010 – May 2011			
Hour	Chesterfield	Henrico	Difference	p-value	Chesterfield	Henrico	Difference	p-value
Midnight – 12:59am	0.28	0.23	0.05	0.766	0.09	0.17	-0.08	0.486
1am – 1:59am	0.00	0.06	-0.06	0.266	0.00	0.00	0.00	N/A
2am – 2:59am	0.14	0.00	0.14	0.119	0.19	0.00	0.19	0.071
3am – 3:59am	0.14	0.06	0.08	0.428	0.00	0.00	0.00	N/A
4am – 4:59am	0.00	0.00	0.00	N/A	0.05	0.00	0.05	0.367
5am – 5:59am	0.09	0.00	0.09	0.204	0.05	0.17	-0.13	0.219
6am – 6:59am	0.47	0.06	0.41	0.018	0.66	0.06	0.60	0.003
7am – 7:59am	2.28	1.04	1.24	0.003	3.14	1.17	1.98	< 0.001
8am – 8:59am	0.84	2.48	-1.64	< 0.001	0.94	2.56	-1.63	< 0.001
9am – 9:59am	0.47	0.23	0.23	0.225	0.52	0.41	0.11	0.625
10am – 10:59am	0.42	0.46	-0.04	0.844	0.56	0.35	0.21	0.335
11am – 11:59am	0.51	0.40	0.11	0.621	0.52	0.41	0.11	0.625
12am – 12:59am	0.88	0.35	0.54	0.037	0.84	0.52	0.32	0.237
1pm – 1:59pm	1.72	0.69	1.03	0.004	2.20	0.87	1.33	0.001
2pm – 2:59pm	4.09	0.75	3.35	< 0.001	4.64	1.11	3.53	< 0.001
3pm – 3:59pm	1.58	1.79	-0.20	0.626	1.73	2.21	-0.48	0.286
4pm – 4:59pm	1.67	2.99	-1.32	0.007	2.58	2.80	-0.22	0.678
5pm – 5:59pm	2.56	2.07	0.49	0.325	2.25	2.33	-0.08	0.868
6pm – 6:59pm	1.95	1.79	0.17	0.702	1.73	2.21	-0.48	0.286
7pm – 7:59pm	1.26	1.32	-0.07	0.852	0.98	1.28	-0.30	0.383
8pm – 8:59pm	1.12	0.69	0.43	0.170	0.75	1.51	-0.76	0.023
9pm – 9:59pm	1.02	0.63	0.39	0.189	0.47	0.93	-0.46	0.080
10pm – 10:59pm	0.70	0.69	0.01	0.980	0.56	0.64	-0.08	0.753
11pm – 11:59pm	0.19	0.12	0.07	0.576	0.28	0.29	-0.01	0.953

N/A, not applicable.

Figure S3—Counties and cities, respectively, with earlier high school start times: Chesterfield County school year crash rates for Sept. 2009–May 2010 and Sept. 2010–May 2011 and Virginia Beach crash rates for January–December 2007 and January–December 2008.

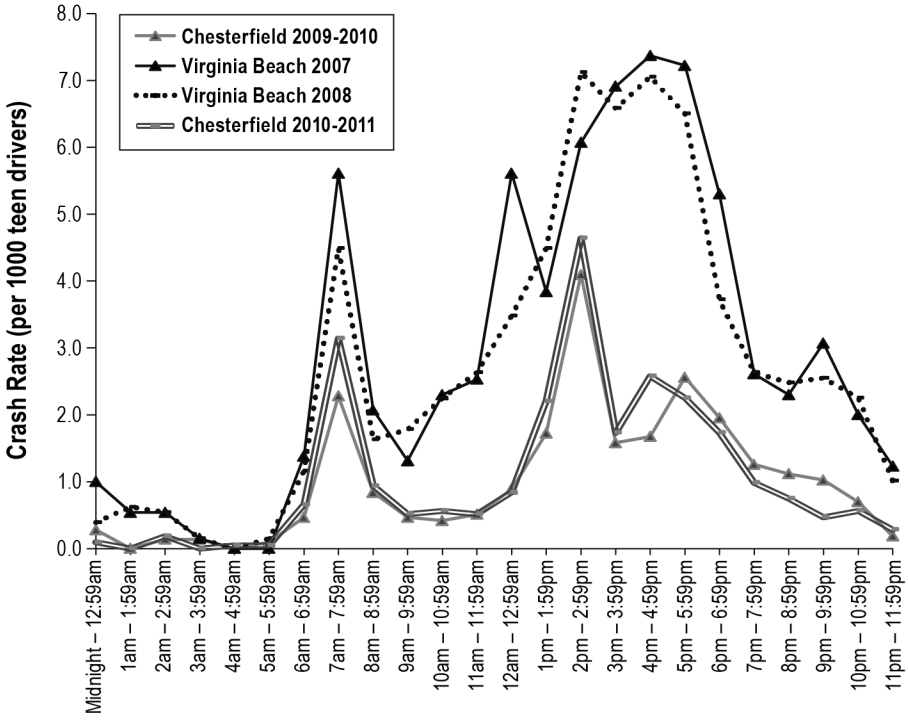

Figure S4—Counties and cities, respectively, with later high school start times: Henrico County crash rates for Sept. 2009–May 2010 and Sept. 2010–May 2011 and Chesapeake City crash rates for January–December 2007 and January–December 2008.

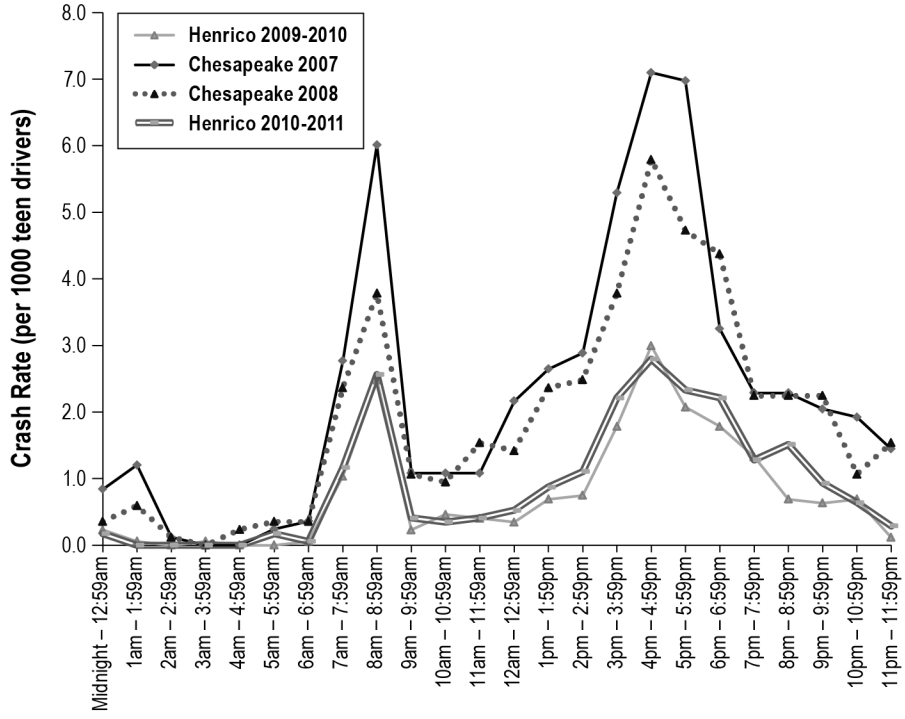

Figure S5—Monthly adolescent (16–18 years) crash rates per 1,000 licensed drivers 16–18 years for Chesterfield County and Henrico County for school years 2009 (Sept. 2009–May 2010) and 2010 (Sept. 2010–May 2011).

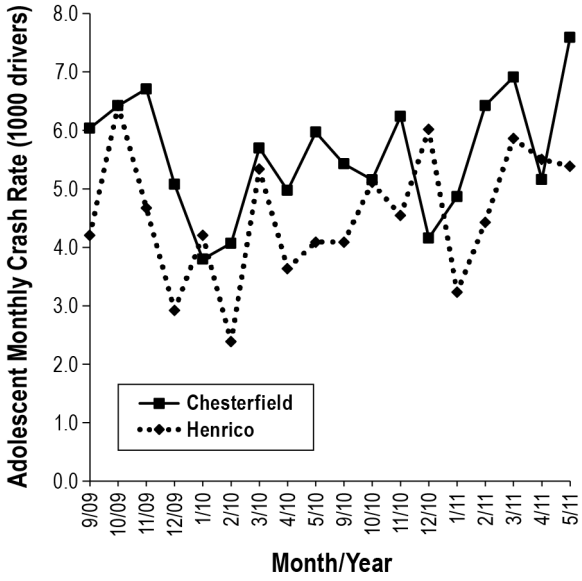

Figure S6—Monthly adult (> 18 years) crash rates per 1,000 licensed drivers > 18 years for Chesterfield County and Henrico County for school years 2009 (Sept. 2009–May 2010) and 2010 (Sept. 2010–May 2011).

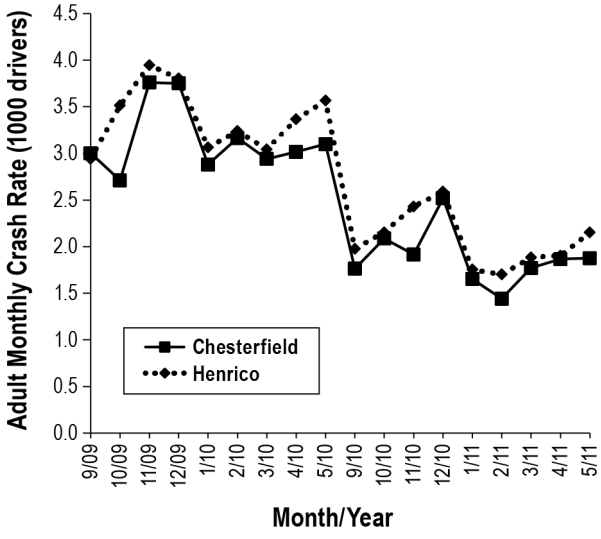

Table S3A—2-year (2009–2010) cause-specific crash rates for adolescent drivers 16–18 years old from the Commonwealth of Virginia Department of Motor Vehicles Police Crash Report data for 2009 and 2010.

Specific Crash Causes* from Commonwealth of Virginia Department of Motor Vehicles Police Crash Report	Specific Causes of Crashes	Chesterfield‡	Henrico‡	Difference	p-value	CI§
Asleep or fatigued from driver condition section†	Apparently asleep	0.0010	0.0003	0.0007	0.080	-0, 0.001
	Fatigued (driver condition)	0.0007	0.0007	0.0001	0.890	-0.001, 0.001
Fatigue from driver distraction section†	Fatigued (driver distraction)	0.0013	0.0008	0.0005	0.295	-0, 0.001
Fall-asleep or fatigued crashes combined from both driver condition and distraction sections of police crash report	Sleep + fatigue (driver condition)	0.0031	0.0018	0.0012	0.090	-0, 0.003
	Sleep + fatigue (driver condition) + fatigue (driver distraction)	0.0018	0.0010	0.0007	0.181	-0, 0.002
Alcohol use from police report	Drinking ability impaired	0.0011	0.0007	0.0004	0.332	-0, 0.001
	Obviously drunk	0.0011	0.0013	-0.0002	0.762	-0.001, 0.001
Run-off road crashes from police report	Ran off road-left	0.0047	0.0031	0.0015	0.089	-0, 0.003
	Ran off road-right	0.0087	0.0050	0.0038	0.002	0.001, 0.006

CI, Confidence Interval. *Crash causation data obtained from the Virginia Department of Motor Vehicles were found under the following headings on the Virginia Department of Motor Vehicles police crash forms: a. Driver Condition data for "Apparently Asleep" and "Fatigued," b. Driver Distraction for "Driver Fatigue" (not overlapping with the Driver Condition category of "Fatigued"), c. Driver Drinking for "Drinking-Ability Impaired" and "Drinking Obviously Drunk" and d. Vehicle Maneuvers for "Run off Road Left" and "Run off Road Right." As many categories were not overlapping, we combined them, as described below. †Fatigue from Driver Condition and from Driver Distraction Section of Police Reports are mutually exclusive categories ‡Data in Table S3A were based on numbers provided in Table S3B. §The Upper or Lower limits very close to 0 (up to three decimal places) are reported as "-0" in the output. Only ran off road-right is statistically significant.

Table S3B—Adolescent (16–18 year old) cause-specific crash rates for 2009 and 2010 from Commonwealth of Virginia Department of Motor Vehicles Police Crash Report data.

Specific Causes of Crashes from Virginia Police Report Data	Chesterfield County				Henrico County			
	Number of crashes			2 year cause-specific crash rates* (%)	Number of crashes			2 year cause-specific crash rates‡ (%)
	2009	2010	Total (9+10)		2009	2010	Total (9+10)	
Apparently asleep	4	7	11	0.1024%	2	1	3	0.0346%
Fatigued (A)	7	1	8	0.0744%	2	4	6	0.0691%
Fatigued (driver distraction)	9	5	14	0.1303%	3	4	7	0.0806%
Fatigued [sleep + fatigue (driver condition) + fatigue (driver distraction)]	20	13	33	0.3071%	7	9	16	0.1843%
Fatigue [sleep + fatigue (driver condition)]	11	8	19	0.1768%	4	5	9	0.1037%
Drinking ability impaired	5	7	12	0.1117%	4	2	6	0.0691%
Obviously drunk	4	8	12	0.1117%	5	6	11	0.1267%
Ran off road-left	25	25	50	0.4652%	11	16	27	0.311%
Ran off road-right	47	47	94	0.8747%	24	19	43	0.4952%
Total licensed drivers 16-18 years old (denominator)	10,434	11,059	21,493	10,747†	8,560	8,805	17,365	8,683§

*2-year crash rates for Chesterfield = number of crashes attributable to specific causes for 2009 + 2010 (total column above)/10,747. †10,747 = (licensed drivers for 2009 + licensed drivers for 2010)/2. ‡2-year crash rates for Henrico = number of crashes attributable to specific causes for 2009 + 2010 (total column above)/8,683. §8,683 = (licensed drivers for 2009 + licensed drivers for 2010)/2.