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Dissimilar Teen Crash Rates in Two Neighboring Southeastern Virginia Cities with Different High School Start Times

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SCIENTIFIC INVESTIGATIONS

Study Objectives: Early high school start times may contribute to insufficient sleep leading to increased teen crash rate. Virginia Beach (VB) and Chesapeake are adjacent, demographically similar cities. VB high schools start 75-80 minutes earlier than Chesapeake's. We hypothesized that VB teens would manifest a higher crash rate than Chesapeake teens.

Methods: The Virginia Department of Motor Vehicles (DMV) provided de-identified, aggregate 2008 and 2007 data for weekday crashes and crash times in VB and Chesapeake for drivers aged 16-18 years ("teens"), and provided 2008 and 2007 crash data for all drivers. Data allowed comparisons of VB versus Chesapeake crash rates for teens (overall and hour-by-hour), and teens versus all other ages. We compared AM and PM traffic congestion (peak hours) in the two cities.

Results: In 2008, there were 12,916 and 8,459 Virginia Beach and Chesapeake 16- to 18-year-old drivers, respectively. For VB and Chesapeake, teen drivers' crash rates in 2008 were 65.8/1000 and 46.6/1000 ($p < 0.001$), respectively, and in 2007 were 71.2/1000 and 55.6/1000. Teen drivers' crash peaks in the morning occurred one hour earlier in VB than Chesapeake, consistent with school commute time. Congestion data for VB and Chesapeake did not explain the different crash rates.

Conclusions: A significantly increased teen crash rate for both 2008 and 2007 occurred in VB, the city with earlier high school start times. Future studies using individual level data may clarify if sleep restriction, circadian dyssynchrony, and sleep inertia might contribute to this increased crash rate.

Keywords: High school, start times, teen crash rates, insufficient sleep

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Research suggests that teens require more than 9 hours of sleep per night in order to function optimally.[1] Insufficient sleep in teens is common[2] and could eventuate in excessive sleepiness[3] and such onerous consequences as academic difficulties, behavioral abnormalities,[4,5] mood disorders and perhaps even increased risk of suicidal ideation.[6]

A potential critical consequence of insufficient sleep in teens is drowsy driving. Fall-asleep crashes tend to be severe, and, of these, 55% have been found to occur in individuals who are 25 years or younger.[7] For the years 2007 and 2008, individuals aged 16-20 years had the highest injury rate from motor vehicle crashes.[8] While individuals aged 15 to 20 years represented only 9% of the U.S. population and 6% of licensed drivers for 2007, 19% of all fatalities in the United States were related to young-driver crashes.[9]

Early high school start times could contribute to insufficient sleep in teenagers[10] and increased motor vehicle crashes. One study found start time to be the main determinant of wake times in adolescents.[11] A recent study revealed that a 30-min delay in high school start time was associated with 45 min of additional sleep on weekday nights and reduced sleepiness.[12] Thus, later high school start times could result in more sleep and better synchronicity with the circadian phase delay found in teens.[3]

BRIEF SUMMARY

Current Knowledge/Study Rationale: There is a paucity of scientific literature that examines the possible contribution of early high school start times to teen driver crash rates. The starkly different public high school start times of two adjacent and demographically similar cities in Southeastern Virginia provided a favorable opportunity to explore this potentially important issue.

Study Impact: Teenagers aged 16-18 in the city with the earlier starting high schools manifested a significantly higher motor vehicle crash rate for the years 2007 and 2008. These results are provocative, but more work (e.g. individual-level data) needs to be performed to better understand if early high school start times are directly associated with an increased risk of crashes in these young drivers.

Unfortunately, the relationship of high school start times to crash rates has rarely been investigated. One recent study by Danner and Phillips did demonstrate that delaying high school start times reduced vehicle crashes in teens. In Lexington Kentucky, a 1-h delay in high school start times was associated with a 16.5% decline in teen crashes in the ensuing 2 years.[13]

Adjacent and demographically similar cities in Southeastern Virginia, Virginia Beach and Chesapeake offer a propitious opportunity to compare further school start times and teen crashes. These adjoining cities have markedly different public high school start times. Virginia Beach begins public high school at 07:25 (one school at 07:20), while Chesapeake public high schools start at either 08:40 or 08:45. Respective dismissals occur at 14:00 (2 pm) (one school at 14:14) and 15:00-15:43. Given previous, albeit limited, research findings, we hypothesized that the early Virginia Beach public high school start time would be associated with an increased driver crash rate among adolescents aged 16-18 years for 2007 and 2008.

Most Virginia Beach and Chesapeake teens attend public schools. Virginia Beach has 11 traditional public high schools, and Chesapeake has seven. Virginia Beach has 22,352 public high school students,[14] and Chesapeake 12,980 students (per Ms. Paige Stutz Chesapeake Public Schools with permission). There are also 4 alternative public high schools (one is a juvenile detention center) in Virginia Beach, as well as private schools in each city.

U.S. Census data from 2000 revealed Virginia Beach to be 71% Caucasian and 19% African American, while Chesapeake was 67% Caucasian and 28% African American. The same census data revealed respective per capita incomes of $22,365 and $20, 949.[15] Both of these Virginia cities occupy large areas of land. Virginia Beach has a land area of 248 square miles; Chesapeake is larger, with 340 square miles.[15] In contrast, in 2008, Virginia Beach had 3380 square miles of improved roads, and Chesapeake had 2329 square miles of improved roads, according to the Hampton Roads Transportation Planning Organization (HRTPO).[16]

METHODS

This study was approved by the Eastern Virginia Medical School (EVMS) Institutional Review Board. The Virginia Department of Motor Vehicles (DMV) supplied de-identified aggregate data for number of weekday (Monday-Friday) crashes and time of crashes for all crashes in which the drivers were ages 16 through 18 years in both Virginia Beach and Chesapeake for years 2008 and 2007. We focused on weekdays, as these are the days of public school attendance and thus, commutes to and from school. We elected to investigate 16- to 18-year-olds in order to be inclusive of all those in high school and provide a more conservative estimate than would be obtained by exclusion of 18-year-olds.

We obtained 2008 and 2007 data from the DMV for crash rates in both cities for teenagers as well as for all drivers. This investigation focused on differences in crash rates in teens in the Virginia cities of Virginia Beach and Chesapeake for 2008 and 2007. As a confirmatory analysis, it was important to ascertain if any differences in crash rates between Virginia Beach and Chesapeake teens were (or were not) replicated by crash rates in all other ages combined in the respective cities. For example, increased crashes in Virginia Beach over Chesapeake, if seen in *both* teens and all other ages, might point to a more systemic problem rather than a problem specific to teens such as school start times.

We conducted several secondary analyses. We examined crash data restricted to 16- and 17-year-old drivers in both Virginia Beach and Chesapeake as a type of sensitivity/confirmatory analysis for our primary analyses of 16- to 18-year-old drivers. We also examined the differences in crash rates between cities for the school year (September 2007 through June 2008), as the main findings shown are for the calendar year. As an ancillary analysis, time of day patterns for crash rates in year 2008 were also presented for 1-h time periods for Virginia Beach and Chesapeake, and differences between the cities analyzed for the times representing the commute time to school. The following statistical analyses were conducted. For the calendar years 2008 and 2007, we compared the difference in teenage (16- to 18-year-old) crash rates between Virginia Beach and Chesapeake using a 2-sample Z-test, with $p \leq 0.05$ considered statistically significant. Ninety-five percent confidence intervals were estimated for this difference in rate proportions. The difference in crash rate (between Virginia Beach and Chesapeake) for 16- to 18-year-olds was also compared to the difference in crash rate for all other ages using a 2-sample Z-test; and 95% confidence intervals were also estimated for these differences in rate proportions. As secondary analyses, we conducted these same analyses, also using a 2-sample Z-test to compare rate proportions, but restricted the analyses to 16- and 17-year-old drivers for 2008. Also, for September 2007 to June 2008, inclusive (traditional school year), we compared the difference in teenage (16- to 18-year-old) crash rates between Virginia Beach and Chesapeake using the methods described above.

Furthermore, as an ancillary analysis, we compared crash rates between Virginia Beach and Chesapeake for 2008, for specific time periods using 2-sample Z-tests to test for statistically significant differences.

As further secondary analyses, we investigated potential differences in traffic conditions between Virginia Beach and Chesapeake. The Hampton Roads Transportation Planning Organization (HRTPO) (http://www.hrtpo.org/), "… the intergovernmental transportation planning body for thirteen jurisdictions in Hampton Roads" supplied data on afternoon traffic congestion for 2008 and morning traffic congestion in 2003 (the last year that they obtained morning data) for Virginia Beach and Chesapeake.

The HRTPO evaluated traffic congestion using number and percentage of non-freeway arterial lane miles by a.m. and p.m. peak hour level of service and percentage of peak hour vehicle-miles of travel (VMT) by a.m. and p.m. peak hour level of service. "Level of service (LOS) is a quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience."[17] Levels of service describe the effectiveness of the transportation infrastructure for conveying traffic.

Roadways were defined as uncongested, moderately congested, and severely congested. HRTPO also furnished the percentage of Chesapeake and Virginia Beach daily VMT during the a.m. and p.m. peak hours. The VMT/driver ratio was also calculated for p.m. hours as a further assessment of congestion. Chi-square tests were conducted to statistically compare the congestion rates between Chesapeake and Virginia Beach for morning and afternoon congestion. (Please see appendices for information on average time of start of a.m. peak hour for each city.)

RESULTS

In 2008, Virginia Beach and Chesapeake had a total of 12,916 and 8,459 drivers, respectively, between the ages of

Table 1—Comparisons of weekday crash rates between City of Virginia Beach and Chesapeake for teenaged ("teen") driver group aged 16-18 years and all other age groups (excludes 16-18 years) combined for Year 2008

	Virginia Beach	Chesapeake	Difference between crash rates in 2 cities	95% confidence interval of difference between 2 cities		p-value
Crash rate for teens 16-18 y (per 1000)	65.8	46.6	19.2	13.0	25.4	< 0.001
Crash rate for all other ages (excluding teenagers 16-18 y) combined (per 1000)	22.2	18.0	4.2	3.4	5.1	< 0.001
Crash rate difference between teens 16-18 y and all other ages combined	43.6	28.6	15.0	12.2	17.8	< 0.001
Crash rate for all ages (per 1000)	24.1	19.6	4.5	3.6	5.4	< 0.001

Table 2—Comparisons of weekday crash rates between City of Virginia Beach and Chesapeake for teenaged ("teen") driver group 16-18 years old and all other age groups (excludes 16-18 year olds) combined for Year 2007

	Virginia Beach	Chesapeake	Difference between crash rates in 2 cities	95% confidence interval of difference between 2 cities		p-value
Crash rate for teens 16-18 y (per 1000)	71.2	55.6	15.6	9.0	22.3	< 0.001
Crash rate for all other ages (excluding teenagers 16-18 y) combined (per 1000)	23.9	20.4	3.5	2.6	4.5	< 0.001
Crash rate difference between teens 16-18 y and all other ages combined	47.3	35.2	12.1	9.2	15.0	< 0.001
Crash rate for all ages (per 1000)	26.0	22.4	3.6	2.7	4.6	< 0.001

Table 3—Comparisons of weekday crash rate between City of Virginia Beach and Chesapeake for teenager ("teen") group aged 16-17 years and all other age groups (excludes 16-17 years) combined in for Year 2008

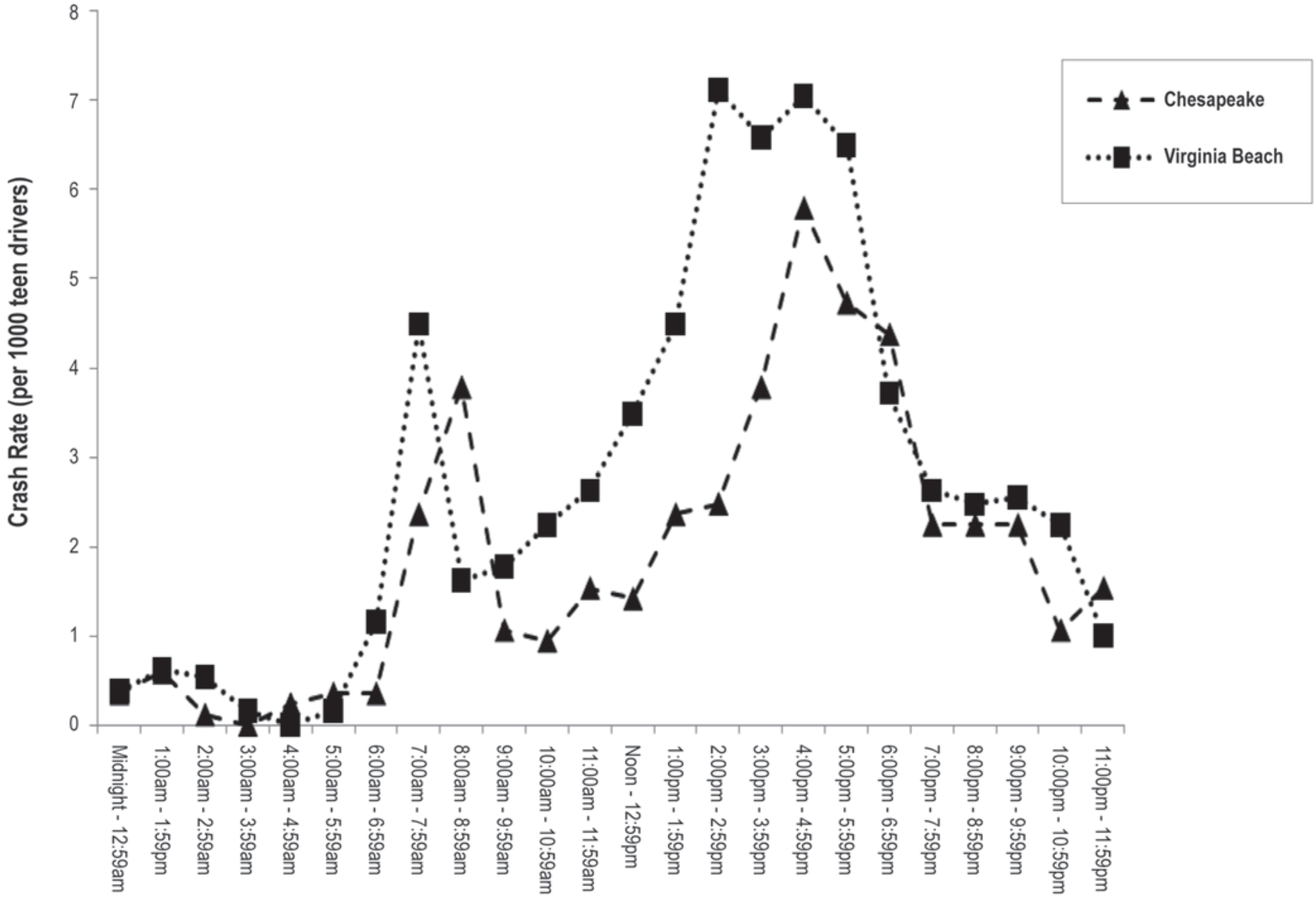
	Virginia Beach	Chesapeake	Difference between crash rates in 2 cities	95% confidence interval of difference between 2 cities		p-value
Crash rate for teens 16-17 y (per 1000)	92.2	65.0	27.2	18.0	36.5	< 0.001
Crash rate for all other ages (excluding teenagers 16-17 y) combined (per 1000)	22.3	17.9	4.3	3.5	5.2	< 0.001
Crash rate difference between teens 16-17 y and all other ages combined	69.9	47.0	22.9	18.5	27.3	< 0.001
Crash rate for all ages (per 1000)	24.1	19.6	4.5	3.6	5.4	< 0.001

16 and 18 years. These teen drivers were involved in 850 and 394 crashes, respectively. As shown in **Table 1**, which demonstrates the weekday 16- to 18-year-old ("teens") crash rates for the cities of Virginia Beach and Chesapeake; this difference of 19.2 per 1000 had a 95% confidence interval (CI) of 13.0/1000 to 25.4/1000 ($p < 0.001$). The crash rate difference between teenagers 16-18 years old and all other age groups (except teenagers) was 43.6/1000 (95% CI, 39.3-47.9) for Virginia Beach and 28.6/1000 (95% CI, 24.1-33.1) for Chesapeake. Thus, the difference between these cities for crash rate among 16- to 18-year-old drivers versus crash rate for all other ages combined was 15.0 per 1000 (95% CI, 12.2/1000, 17.8/1000). (**Table 1**) The overall crash rate for all ages shown in **Table 1** was based on the following data for 2008: a total of 7,258 motor vehicle crashes among 301,218 licensed drivers in Virginia Beach; and 2,977 crashes among152,110 drivers in Chesapeake

The results for 2007 were similar and show that the difference between Virginia Beach and Chesapeake for crash rates among 16- to 18-year-olds was almost replicated for another year (**Table 2**). In the year 2007, Virginia Beach had 13,018 registered drivers 16-18 years of age and 927 crashes involving teenaged drivers 16-18 years, while Chesapeake had 8,315 registered teenaged drivers 16-18 years and 462 crashes involving these teenaged drivers. As shown in **Table 2**, which demonstrates the weekday 16- to 18-year-old crash rates for the cities of Virginia Beach and Chesapeake, this difference in crash rates of 15.6 per 1000 had a 95% CI of 9.0/1000 to 22.3/1000 ($p < 0.001$). The crash rate difference between teenagers 16-18 years old and all other age groups (except teenagers 16-18) was 47.3/1000 (95% CI, 42.8/1000 to 51.7/1000) for Virginia Beach and 35.2/1000 (95% CI, 30.2/1000 to 40.1/1000) for Chesapeake. Thus, the difference between these cities for crash rates among 16- to 18-year-old drivers versus crash rate for all other ages was 12.1 per 1000 (95% CI, 9.2/1000 to 15.0/1000) (**Table 2**)

As a confirmatory analysis, 18-year-old drivers were removed from the 2008 data. Results for 16- and 17-year-olds (excluding 18-year-olds) showed no attenuation of the crash rate difference (27.2/1000, 95% CI 18.0/1000 to 36.5/1000) (**Table 3**) between Virginia Beach and Chesapeake (**Table 3**). The crash rate difference between teenagers 16-17 years old and all other ages combined (except teenagers 16-17) was 69.9/1000 (95% CI, 63.5/1000 to 76.3/1000) for Virginia Beach and 47.0/1000 (95% CI, 40.3/1000 to 53.7/1000) for Chesapeake. Thus, the

Figure 1—Weekday crash rate of 16- to 18-year age groups in Chesapeake and Virginia Beach for year 2008



difference between these cities for crash rate among 16- and 17-year-old drivers versus crash rate for all other ages was 22.9 per 1000 (95% CI, 18.5/1000 to 27.3/1000).

Another secondary analysis involved evaluation of only the traditional school months, namely, September 2007 through June 2008. Results were that 16- to 18-year-old Virginia Beach drivers still manifested a greater crash rate (80.0/1000) than Chesapeake (64.0/1000), with a crash rate difference of 16.0/1000 (95% CI of 9.0/1000 to 23.0/1000).

Regarding the temporal pattern (time of day of crashes) of teen crashes, **Figure 1** demonstrates weekday crash rates for ages 16-18 years by time of day for 2008. The patterns are similar for the times representing the commute to school. Furthermore, the morning peaks for each city occurred during what is likely the commute to school, 07:00-07:59 for Virginia Beach and 08:00-08:59 for Chesapeake. Peak morning 16- to 18-year-old driver vehicular crash rates for 2008 in Virginia Beach occurred an hour earlier than in Chesapeake. Thus, from 07:00-07:59, the crash rate for Virginia Beach was 4.49 per 1000, compared to 2.13 for Chesapeake, and this difference of 2.13/1000 was statistically significant ($p = 0.007$). From 08:00-08:59, the crash rate for Chesapeake was higher (3.78 per 1000 compared to 1.63/1000 for Virginia Beach), and this difference of 2.16/1000 was also significant ($p = 0.004$). Thus the differences in crash rates between cities for 07:00-07:59 and 08:00-08:59 were similar (with Virginia Beach higher for one, and Chesapeake for the other), likely reflecting the different commute times to school.

For 2007, the differences in crash rates for times corresponding to commute times were similar. The increased crash rate of 5.61/1000 for Virginia Beach, relative to Chesapeake (2.77/1000), for 07:00-07:59, resulted in a difference of 2.84/1000, which was statistically significant ($p = 0.001$); the increased crash rate for Chesapeake (6.01/1000) relative to Virginia Beach (2.07/1000) from 08:00-08:59, resulted in a significant difference of 3.94/1000 ($p < 0.001$).

There were also peaks in the afternoon in both cities. In Virginia Beach, the peak crash rates for these teens were 7.12/1000 and 7.05/1000 and occurred at 14:00-14:59 and 16:00-16:59, respectively. The rates for 15:00-15:59 and for 17:00-17:59 were similarly elevated (6.58/1000 and 6.50/1000, respectively). Thus, the greatest crash rates for Virginia Beach spanned a broad time frame from 14:00-18:00. In Chesapeake, the greatest rate (5.79/1000) occurred from 16:00-16:59. However, crash rates persisted, elevated from 17:00-17:59 (4.73/1000) and 18:00-18:59 (4.37/1000). Although the differences in rates between Virginia Beach and Chesapeake were significantly higher in Virginia Beach than Chesapeake rates at 14:00-14:59 and 15:00-15:59 (2.80/1000, $p = 0.004$) and (4.6/1000, $p < 0.0001$), the patterns for both cities were similar. Also, the afternoon crash rates for the 2 cities were not significantly different between 16:00-21:00.

Regarding our secondary analyses, we evaluated traffic congestion in Virginia Beach and Chesapeake via data supplied by the Hampton Roads Transportation Planning Organization (HRTPO). In 2003, Chesapeake manifested higher peak hour vehicle-miles of travel by a.m. level of service ($p < 0.0001$), and in 2008, there were no differences in peak hour vehicle-miles of travel (VMT) by p.m. level of service ($p = 0.328$). In addition, the afternoon p.m. peak VMT/driver was similar for Chesapeake and Virginia Beach: 1.47 (223,138/152,110) and 1.44 (423,803/301,218), respectively. Additional tables are provided in the appendix (available online at www.aasmnet.org/jcsm).

CONCLUSIONS

This study's primary findings revealed an elevated weekday crash rate among the 16- to 18-year-old drivers in Virginia Beach over Chesapeake. The increased crash rate difference for 16-to 18-year olds (Virginia Beach greater than Chesapeake) versus all other ages further supports our findings. Findings of statistically significantly elevated teen crash rate and an increased ratio of teen crashes to crashes in all other ages for Virginia Beach were similar for both 2007 and 2008. This reproducibility adds to the strength of our findings.

Among all drivers (excluding those aged 16-18 years), Virginia Beach does manifest an overall higher crash rate than Chesapeake; however, this difference is far less pronounced than the striking difference found between 16- to 18-year-old drivers in Virginia Beach versus Chesapeake. The difference in teen crashes between cities was 4.5 times higher than the crash rate difference for all other ages, a further confirmation of our findings.

In this study, the city (Virginia Beach), with a markedly earlier high school start time has a higher teenage crash rate. As noted, teenagers in Virginia Beach must start school 75-80 minutes earlier than in Chesapeake. Our study does not have subjective or objective (e.g., actigraphy) data on teenagers' sleep times in Virginia Beach and Chesapeake to more strongly link sleep loss to crash rate. This would be of interest and should be pursued in future work. However, previous data indicate that earlier rise times in teens are not correlated with earlier bedtimes.[3]

Our findings may indicate that Virginia Beach teenagers are sleep restricted. An increased pressure to sleep may explain the increased rate of teen crashes when school start times are more than an hour earlier. In addition, early start times such as are seen in Virginia Beach conflict with neurophysiology. For a teen arising at 06:00 to achieve at least 9 hours of sleep, he or she would have to go to bed by 21:00. Beyond the impracticality of getting a high school student in bed by 21:00, teen delayed circadian rhythms work against such an early bedtime. These teens may suffer from circadian delays in addition to sleep deprivation, which may place them at a heightened risk for crashes. Sleep deprivation may also be related to increased risk-taking proclivity,[5] which might relate to increased crash rates.

As an ancillary analysis, we examined the temporal patterns of teenage crashes in the two cities, especially for the morning times corresponding to the commute to school. Both cities manifested an early morning peak which likely coincides with the commute to school. A circadian vulnerability may underpin the increased crash rate noted in teens in both cities. In addition, this early morning peak could be a consequence of "sleep inertia," which could contribute to the increased crash rates in both cities in the early morning. Teens in both cities could awaken shortly before driving and then drive their vehicles during this time of sleep inertia compromise.[18] Research has demonstrated that even 30 minutes after awakening there can be a 20% decrement in performance.[19] Our ancillary analysis also revealed peaks in afternoon crash rates in both cities, with Virginia Beach showing a greater afternoon crash rate than Chesapeake. Again, we believe that the timing of crashes may relate to the commute home, and that an afternoon circadian dip in alertness could be one culprit. Although peak afternoon times were consistent with drive home times from school, it is difficult to assess exactly when this time occurred, perhaps given teens' variable after school schedules including school activities, athletics, and work.

The finding of increased crashes during apparent commute times in teens replicated findings from a 2007 Fairfax County, Virginia study that also demonstrated more crashes both before and after school.[20] Other differences in the timing of the two cities teens' crash rates, e.g., around lunch time, are not easily explained. Both school systems have a closed lunch policy, meaning students cannot leave campus. Previous work has associated open lunch policy in North Carolina with student lunch hour crashes.[21] Hourly crash rates for September 2007 through June 2008 or for 16- and 17-year-old drivers (as opposed to 16- to 18-year-olds) could be informative data for subsequent research.

Strengths of the present study include the immediate geographical proximity of these two cities (thus limiting concerns about complicating factors such as different weather or seasonal conditions) and a near replication of the data for two consecutive years. Other strengths include obtaining data from the Virginia Department of Motor Vehicles for all 16-to 18-year-old drivers in each city, and the similar demographics in the two cities. Further, the driving conditions should be similar, in that neither city has a truly urban layout.

We are cognizant of several limitations to this study beyond absence of documentation of sleep amounts. Both the potential risk exposure (in this case school start times) and the outcome (crashes) are aggregate measures. Our findings need to be replicated using individuals as the analytic units. Therefore, as we examined aggregate data, we could not gather individual driver data. Hence, some crashes may be repetitive crashes by the same teen driver. Crash rates may also be affected by unmeasured factors other than school start times, which could help to explain the differences observed; due to aforementioned aggregate data, these could not be examined. For example, a recent study of Italian teens associated factors such as poor sleep and cigarette abuse with crashes.[22] One potential limitation is that we were unable to assess alcohol use as a factor in the crashes of 16- to 18-year-olds. This information was also not included by DMV as a cause of crashes in 16- to 18-year-old drivers in Virginia Beach and Chesapeake. Future research might also examine variations in changing light levels (e.g., time of sunrise); especially during the peak driving times (such as commute to or from school). Finally, it would be of great interest to learn what percentage of these teen crashes occurred specifically as a consequence of sleepiness. DMV data established that the most common causes for crashes in 16- to 18-year-old drivers in Virginia Beach and Chesapeake in 2008 and 2007 were "no improper action" and "following too close." However, sleep related factors (drowsy driving, falling asleep at the wheel) were not listed as causes of crashes in the DMV crash data for Virginia Beach and Chesapeake.

Afternoon congestion data for 2008 demonstrated no differences between Virginia Beach and Chesapeake, and morning data (albeit from 2003) revealed greater congestion in the city of Chesapeake. These data from the Hampton Roads Transportation Planning Organization thus suggest that a difference in congestion between the two cities was not a critical arbiter of the increased crash rate found in Virginia Beach teens. Although we attempted to gather data on vehicle miles traveled (VMT) by students in Virginia Beach and Chesapeake, such data on VMT specifically for teen drivers in Virginia Beach and Chesapeake were not available. This could be construed as a possible study limitation. However, we obtained VMT data for all drivers as a measure (even if less precise) of traffic congestion. Regarding the ratio of VMT to total drivers as a measure of congestion, results indicated the cities were similar, further suggesting that the difference in teenage rates may instead relate to school start times**.**

Another potential limitation of our study is the inclusion of 18-year-old drivers who could be college students or no longer attending school. We did not wish to miss any high school students in this age category, and hence, we included 18-year-olds in our analysis to provide a more sensitive definition, with the potential limitation of loss of specificity. However, our analysis of Department of Motor Vehicles data for 16- and 17-year-old drivers in Virginia Beach and Chesapeake demonstrated a similar increased crash rate in Virginia Beach versus Chesapeake. Thus, we believe our addition of 18-year-old drivers in the two cities provided a more conservative estimate.

Teens are vulnerable drivers, and this study unsurprisingly demonstrates that Virginia Beach and Chesapeake teens manifest a higher crash rate than do other drivers in these two Southeastern Virginia cities.[23] We evaluated crash rates only for 16- to 18-year-olds and all other ages combined. Although it might also have been of interest to systematically compare Virginia Beach and Chesapeake drivers' crash rates throughout other ages, and compare these to teen rates, for the present study, we focused on differences between these two cities' teen drivers, as this was our primary objective. We looked at all other drivers combined to assure ourselves that the marked differences between Virginia Beach and Chesapeake teens were not merely replicated by all other drivers combined.

We have not included gender effects on teen crashes in these two cities, as we believe that such an analysis is beyond the scope of this study. However, these data can be found in an accompanying appendix (available online at www.aasmnet.org/jcsm).

Since we did not have individual-level data, we were unable to assess additional factors that might help explain these crash rate differences, such as contextual or cultural factors impacting adolescent sleep habits[24] or personal work or other activity (e.g., athletics) schedules before and after school. Of concern, a recent study showed that most teens worked about 16.2 hours a week, 82% after 19:00 on school nights, and over half after 21:00.[25] Finally, unreported crashes could occur in our study population (e.g., if students are uninsured and police reports are not filed). We are not aware of any reason, however, why teen crashes in Virginia Beach would be more or less likely to be reported than in Chesapeake.

We did not assess crash severity. Future studies might explore whether the earlier high school start times in Virginia Beach were also related to vehicular crashes marked by increased injury or mortality rates. We further caution that these findings cannot be generalized to cities which differ demographically or which are not geographically contiguous.

This study did not assess crash rates specifically for students at individual schools that are private or non-traditional. In Virginia Beach for the year 2009-2010, 10% of K-12 students (7749 of 71,198) attended private schools.[26] In Chesapeake for the same year, 12% of K-12 students (5475 of 45,358) attended private schools.[27] Thus, the focus on public schools is a potential limitation to this study. As regards all non-traditional Virginia Beach schools, establishing specific attendance figures is problematic. Only one of the alternative Virginia Beach schools (with 785 students) is counted separately from the local high school (spokesperson for Virginia Beach Public Schools 05/11/2010). The three other alternative schools apparently include their students in these students' neighborhood high school attendance data. Of interest, the three schools excluding the juvenile detention center offer both morning and afternoon sessions. These three schools have morning sessions that begin at 07:25, 07:45, and 07:45, and thus all morning sessions begin earlier than Chesapeake public schools. The later Virginia Beach sessions begin at 15:30, 11:20, and 11:20.[28]

Our findings lend support to the argument against earlier high school start times. Although our study design was distinct from that of Danner and Phillips,[13] our results were consistent with their findings demonstrating a decline in teen crashes associated with a one-hour delay in high school start times. Based on our own 2008 results, we estimate that 16 crashes could be prevented yearly if the crash rate in Virginia Beach approximated the rate in Chesapeake.

Beyond driving safety, improved academic performance subsequent to delayed high school start times is another important possible benefit. Wahlstrom et al.[29] analyzed the effects of later school start times in seven districts in Minnesota and found that high school pupils reported increased attendance rates, especially when start times were delayed by one hour.

If high school start times (and dismissal times) are to be delayed, further research along the lines of the present one may help guide recommendations regarding school start times. We suggest further studies to clarify the effects of later high school start times on adolescents and to help reduce preventable crashes in this susceptible population.

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APPENDIX

Table S1—Number and percentage of lane miles by PM peak hour level of service,* 2008

Jurisdiction	PM PEAK HOUR LEVELS OF SERVICE (LOS)* Uncongested LOS A, B, or C†		Moderate Congestion LOS D		Severely Congested LOS E or F		Total Lane-Miles	
Chesapeake	340.38	68.9%	99.22	20.1%	54.63	11.1%	494.23	100%
Virginia Beach	513.52	62.7%	191.28	23.3%	114.44	14.0%	819.24	100%

Only includes non-freeway arterials. *Level of service (LOS) is a quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience.[a] Levels of service are categorized as A-F with A being best and F the worst. PM peak hour level of service is defined as 1500-1900 (per HRTPO). †LOS A, B, and C are defined by industry standards as uncongested. ‡LOS D is defined as moderate congestion. §LOS E and F are defined as severely congested. Source: HRTPO, 9/9/2010.

Table S2—Percentage of peak hour vehicle-miles of travel (VMT) by PM peak hour level of service, 2008

Jurisdiction	PM PEAK HOUR LEVELS OF SERVICE Uncongested LOS A, B, or C†		Moderate Congestion LOS D‡		Severely Congested LOS E or F§		Total Peak Hour VMT	
Chesapeake	120,481	54.0%	58,275	26.1%	44,382	19.9%	223,138	100%
Virginia Beach	235,616	54.4%	102,253	23.6%	94,934	21.9%	432,803	100%

Only includes non-freeway arterials. *Level of service (LOS) is a quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience.[a] Levels of service are categorized as A-F with A being best and F the worst. PM peak hour level of service is defined as 1500-1900 (per HRTPO). †LOS A, B, and C are defined by industry standards as uncongested. ‡LOS D is defined as moderate congestion. §LOS E and F are defined as severely congested. Source: HRTPO, 9/9/2010.

Table S3—Percentage of peak hour vehicle-miles of travel (VMT) by PM peak hour level of service, 2008

Jurisdiction	PM PEAK HOUR LEVELS OF SERVICE Uncongested LOS A, B, or C†		Moderate Congestion LOS D‡		Severely Congested LOS E or F§		Total Peak Hour VMT		Total registered drivers	PM Peak VMT/Driver
Chesapeake	120,481	54.0%	58,275	26.1%	44,382	19.9%	223,138	100%	152,110	1.47
VA Beach	235,616	54.4%	102,253	23.6%	94,934	21.9%	432,803	100%	301,218	1.44

PM peak hour level of service is defined as 1500-1900 (per HRTPO, 9/9/2010). *Level of service (LOS) is a quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience.[a] Levels of service are categorized as A-F with A being best and F the worst. †LOS A, B, and C are defined by industry standards as uncongested. ‡LOS D is defined as moderate congestion. §LOS E and F are defined as severely congested.

Table S4—Number and percentage of lane miles by AM peak hour level of service, 2003

Jurisdiction	AM PEAK HOUR LEVELS OF SERVICE Uncongested LOS A, B, or C†		Moderate Congestion LOS D‡		Severely Congested LOS E or F§		Total Lane-Miles	
Chesapeake	328.58	71.4%	87.50	19.0%	44.32	9.6%	460.40	100%
Virginia Beach	687.98	87.3%	71.28	9.0%	28.50	3.6%	787.76	100%

Only includes non-freeway arterials. *Level of service (LOS) is a quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience.[a] Levels of service are categorized as A-F with A being best and F the worst. AM peak hour level of service defined as from 0500-0900. †LOS A, B, and C are defined by industry standards as uncongested. ‡LOS D is defined as moderate congestion. § LOS E and F are defined as severely congested. Source: HRTPO, 9/15/2010.

[a]Highway Capacity Manual. Transportation Research Board, Washington, DC. 2000. ISBN 0-309-06681-6.

Table S5—Percentage of peak hour vehicle-miles of travel (VMT) by AM peak hour level of service, 2003

	AM PEAK HOUR LEVELS OF SERVICE							
Jurisdiction	Uncongested LOS A, B, or C†		Moderate Congestion LOS D‡		Severely Congested LOS E or F§		Total Peak Hour VMT	
Chesapeake	95,075	59.6%	38,152	23.9%	26,272	16.5%	159,499	100%
Virginia Beach	264,907	81.9%	39,049	12.1%	19,658	6.1%	323,614	100%

Only includes non-freeway arterials. *Level of service (LOS) is a quality measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience.[a] Levels of service are categorized as A-F with A being best and F the worst. AM peak hour level of service defined as from 0500-0900. †LOS A, B, and C are defined by industry standards as uncongested. ‡LOS D is defined as moderate congestion. §LOS E and F are defined as severely congested. Source: HRTPO, 9/15/2010. [a]Highway Capacity Manual. Transportation Research Board, Washington, DC. 2000. ISBN 0-309-06681-6.

Table S6—Existing AM characteristics, 2003

Jurisdiction	% of City's Daily VMT During AM Peak Hour	Average Time of Start of AM Peak Hour
Chesapeake	7.38%	7:12
Virginia Beach	6.50%	7:27

Only includes non-freeway arterials. VMT, Vehicle Miles Traveled. AM peak hour level of service defined as from 0500-0900. Source: HRTPO, 9/15/2010.

Table S7—Comparisons of crash rate between two genders within each city in years 2007 and 2008

		Chesapeake					Virginia Beach				
Year	Gender	Drivers	Crashes	Crash Rate	Difference	p-value	Drivers	Crashes	Crash Rate	Difference	p-value
2007	Male	4584	335	0.073	0.007	0.263	7280	636	0.087	0.025	< 0.001
	Female	3731	298	0.080			5738	642	0.112		
2008	Male	4355	278	0.064	0.002	0.783	6725	559	0.083	0.014	0.007
	Female	4104	269	0.066			6191	600	0.097		

Table S8—Weekday crash rate of 16-18 year old age group in Chesapeake and Virginia Beach for year 2008 (corresponds to Figure 1)

	Chesapeake crash rate	Virginia Beach crash rate	Difference	p-value
Midnight - 12:59am	0.35	0.39	0.03	0.9036
1:00am - 1:59am	0.59	0.62	0.03	0.9343
2:00am - 2:59am	0.12	0.54	0.42	0.0732
3:00am - 3:59am	0.00	0.15	0.15	0.1573
4:00am - 4:59am	0.24	0.00	-0.24	0.1573
5:00am - 5:59am	0.35	0.15	-0.20	0.3895
6:00am - 6:59am	0.35	1.16	0.81	0.0263*
7:00am - 7:59am	2.36	4.49	2.13	0.0073*
8:00am - 8:59am	3.78	1.63	-2.16	0.0044*
9:00am - 9:59am	1.06	1.78	0.72	0.1627
10:00am - 10:59am	0.95	2.25	1.30	0.0150*
11:00am - 11:59am	1.54	2.63	1.10	0.0776
Noon - 12:59pm	1.42	3.48	2.07	0.0018*
1:00pm - 1:59pm	2.36	4.49	2.13	0.0073*
2:00pm - 2:59pm	2.48	7.12	4.64	0.0000*
3:00pm - 3:59pm	3.78	6.58	2.80	0.0042*
4:00pm - 4:59pm	5.79	7.05	1.25	0.2587
5:00pm - 5:59pm	4.73	6.50	1.77	0.0851
6:00pm - 6:59pm	4.37	3.72	-0.66	0.4635
7:00pm - 7:59pm	2.25	2.63	0.39	0.5729
8:00pm - 8:59pm	2.25	2.48	0.23	0.7322
9:00pm - 9:59pm	2.25	2.55	0.31	0.6500
10:00pm - 10:59pm	1.06	2.25	1.18	0.0309*
11:00pm - 11:59pm	1.54	1.01	-0.53	0.2980

*Statistically significant at $p \leq 0.05$

Figure S1—Weekday crash rate of 16- to 18-year age groups in Chesapeake and Virginia Beach for year 2007