Early morning road crashes: the effects of age and gender.

Smith, S.S., Armstrong, K., Steinhardt, D., Haworth, N.
Centre for Accident Research and Road Safety – QLD
Queensland University of Technology
Email: simon.smith@qut.edu.au

Abstract

Crash frequency is typically much lower during the night than during the day, but it is well recognized that driving at night has a much higher risk relative to traffic exposure. The timing and magnitude of this increased risk is less well understood. The intent of this study was to identify the temporal position of the nighttime crash peak, and to estimate the odds of crash while driving at each hour of the day. Data included crashes registered in Queensland Transport's Road Crash Database for the period mid 2000 to mid 2006 (for all crash severity levels), across urban and non-urban geographical areas. Analyses were restricted to passenger vehicles (cars, station wagons, utility vehicles and 4-wheel drives). Crashes where blood alcohol content was greater than zero was recorded were also excluded. Significant age and gender differences were found for a peak in early morning crash risk. Young males had more than six times the odds for crashes resulting in fatality or hospitalization crash at this time of day. The 2-3am peak is consistent with international findings that suggest sleepiness, rather than darkness, as the primary contributor to these crashes.

Keywords

Road crashes, time of day, nighttime driving, risk, sleepiness

Introduction:

Crash frequency is typically much lower during the night than during the day, but this is predominantly due to the higher daytime traffic volumes. It is has been recognized since 1949 that driving at night has a much higher risk relative to traffic exposure [1]. This increased risk has been reported for all age groups, but is disproportionately high, up to three or four times the risk, for young drivers [2-5]. There are a limited number of studies that have estimated risk of driving at night as a function of distance driven. Both Mortimer and Fell [6] and Massie et al. [7] examined U.S. fatal crash involvement risk across age groups. Both reported that night time crash rates were highest for young drivers, and also higher for drivers aged over 65 than for middle-aged drivers (a U-shaped curve). Relative risk estimates indicated that young drivers have the highest relative risk for fatal crash, followed by drivers in the middle of the age range, with older drivers having lowest relative risks. Williams [8] found a similar pattern for fatal crash relative risk, but found no clear age-related patterns for overall crash risk.

Increased risk of crash at night is found predominantly for fatal crashes [9], and the impact of night driving on overall risk of crash is less certain. For non-fatal injury crashes, relative risk is increased in young drivers, but not to the same extent as for fatal crashes [7]. In contrast, data cited by Williams and Ferguson [2], suggest that the overall risk of crashing for 17 year old drivers is not substantially increased at night (27 versus 28 crashes per million miles travelled). Non-fatal crashes can still have very substantial health and economic consequences. As such, the risk of crashing at night needs to be understood for all levels of crash severity.

Increased relative risk of crash (both fatal and non-fatal) at night has been attributed to a number of factors, including the effects of impaired vision, alcohol, driver inexperience and fatigue [10]. Driving in darkness has been proposed as one potential cause of nighttime accidents, because of poor visibility and perhaps reduced stimulation. There is an extensive literature examining nighttime contrast loss, the effects of headlight glare, and age-related vision decline in driving safety [10-12]. It has also been suggested that improved road lighting could reduce collisions at night [1, 13] in specific locations. Despite these suggestions, most data do not support a difference in road crash during the night between roads that are lit or unlit [14, 15]. Åkerstedt (2001 [16]), for example, presented an analysis of light and dark (due to seasonal variation in high latitudes) that did not support a strong effect of darkness on the frequency of road crash.

The contribution of inexperience and related 'more risky' driving style to nighttime crash has been proposed as a major contributor to increased risk of nighttime crash, particularly for young drivers (see [17] and [2] for extensive reviews). Low traffic volumes have been associated with increased high-speed and fatal crashes [18], and lower traffic volumes at night may potentiate the effects of inexperience. These potential contributory factors generally predict a 'rectangular' function for relative risk. That is, crash risk should rise with the onset of dark, and fall with the onset of light, relative to traffic volumes.

Alcohol has been attributed as the major cause of almost 10% of single and multiple motor vehicle crashes, and almost 40% of traffic fatalities in the United States (US Department of Transportation, National Center for Statistics and Analysis 1998; cited in [19]). Australian data indicates that 44% of all drivers and motorcycle riders killed in road crashes in 1981 had a blood alcohol concentration (BAC) of 0.050 gm/100ml or greater, reducing to 26% in 1998 [20]. The greatest risk for alcohol-related accidents occurs during the night, particularly in the early morning hours [21]. Alcohol has many central nervous system effects that can impair driving skills. In simulator studies, these effects are seen as a tendency to track towards the middle of the road, for increased variability in speed and lane position, and increased frequency of driving off the simulated road [19]. Alcohol use has social determinants, and is therefore likely to distort the temporal pattern of crash risk.

Sleepiness[1] is now also recognized as a substantial contributor to road crashes (see Horne [22] for an extensive early review). Estimates of this contribution have been plagued by methodological inconsistencies, but the best available data suggests a population attributable risk associated with acute sleepiness of at least 19% for fatal or severe crash [23, 24]. The mechanisms for the action of sleepiness on critical driving skills has been well demonstrated in both laboratory-based simulator studies [25], and controlled on-road studies

---

[1] Sleepiness is often alternatively described as 'fatigue', although that term is better understood as an interaction between sleepiness, time on task, and the demands of the road environment.

[26].   Drivers are typically most sleepy at night [27], due to the coincidence of sleep homeostatic and circadian-mediated drives for increased sleep propensity [28].

These mechanisms generally predict increased crash risk later in the night (rather than immediately at the onset of darkness)[2]. This prediction is supported by findings of increased crash risk between midnight and 6a.m. [29, 30], and even more specifically between 3am and 5am [21]. Also consistent with the impact of sleepiness on crash prevalence is a smaller secondary peak in the number of accidents corresponding with the circadian-mediated 'post-lunch dip' in performance [31, 32]. The diurnal profile in road crashes does have some less consistent properties that may reflect time-on-task effects, especially after 2-4 hours of driving (see Folkard et al. [30]). These effects may be more apparent in rural and commercial driving than in shorter, urban, discretionary trips.

In response to identification of sleepiness as a causal factor in crashes, many jurisdictions now specifically identify 'fatigue-related crash'. A number of papers have presented data on time-of-day of crash for fatigue-attributed crash. In those cases, either an observer criteria have been applied (e.g. police at scene decision that fatigue was a contributing factor), or another data criterion has been applied (e.g. a single vehicle crash occurring on a rural, high speed road; see [27, 33]). There are two potential limitations to this approach. The first is practical: fatigue definitions vary considerably between jurisdictions, making attribution and comparisons difficult. The second is conceptual, in that the fatigue reporting tend to reflect cases where fatigue is the obvious contributor to the crash after all other causes have been rejected [33]. The relative contribution of all night-time driving factors has been very difficult to evaluate. Laboratory studies typically partition the factors out, while they may very often co-occur in various combinations on the road. As such, the contribution of sleepiness to all crashes, and particularly to urban crashes, may be underestimated.

Most previous research has examined the temporal pattern of fatal crash or injurious crash [16], serious crash [34], defined 'sleepiness-related' crash [27, 35, 36], or to special populations such as young adults [8]. These analyses are likely to underestimate the risk of crash associated with time of day by not including the majority of crashes, or by having data restricted by imprecise or inaccurate definitions of fatigue. Only one study, by Åkerstedt et al. [16], has specifically identified the position and magnitude of the nighttime crash peak for highway driving. Cases with involvement of alcohol were excluded, but they did include non-fatal crashes. An acute peak in relative risk was identified at 4am. The odds ratio for risk relative to 10-11am (minimum risk) was approximately 5 for crashes associated with injury, and approximately 11 for crashes associated with death. The acute peak in risk at 4am is not consistent with explanations for risk based on reduced visibility, inexperience alone, or with alcohol use alone.

The relative risk of crash for each hour of the day, for all crash types is needed to better understand the contribution of night-time driving factors to road crash. The aim of this study was to identify the position and magnitude of any nighttime peak in crash risk, and to determine this peak at different levels of crash severity across age groups and by gender.

---

[2] The alertness minimum varies between individuals based on their circadian phase position relative to clock time. As such, the resolution of a night-time crash peak has a relationship to the homogeneity of phase in the sample population.

Method

Data included crashes registered in Queensland Transport's Road Crash Database (see Web Crash[3]) for the period 1st July 2000 to 30th June 2006 for all crash severity levels, including; property damage, medical treatment, hospitalization, & fatal crash. Data was treated as two regional categories; 1) Brisbane City Council region (urban region), and 2) the rest of Queensland (predominantly non-urban region). Data on all police reported crashes in the Brisbane City Council local government region in Brisbane and for non-urban areas (all regions) were obtained from road crash statistics provided by Queensland Transport (derived initially from Queensland Police traffic accident and coroners reports). Analyses were restricted to passenger vehicles (cars, station wagons, utility vehicles and 4-wheel drives). Crashes where blood alcohol content was greater than zero, or was unknown, or the driver refused a test, were excluded. Crashes where BAC testing was recorded as 'not required' were included in the data. Cases where either age or gender were unreported, reported as 'unknown', or age was less than 17, were also excluded. This data included 30,896 reported road crashes for the BCC urban region, and 77,114 crashes for the non-urban region (a total of 108,010 crashes). The recorded crashes were characterized by level of severity; for all crash severity levels; property damage, medical treatment, hospitalization, & fatal crash.

Traffic flow estimates (vehicles per hour and day) for the urban region were obtained from hourly Brisbane City Council traffic light counts for each day of 2006. This daily data was collated to provide a mean estimate of relative traffic volume for each hour of the day (example in Figure 1a). Accurate traffic volume estimates were not available for most of rural and remote Queensland. A proxy estimate of non-urban traffic flow was derived from Annual Average Daily Traffic (AADT) [37] counts for the North-West NSW region (a region geographically close to South-West Queensland) conducted for one week in August 2005 (Figure 1b). Because of these differences in the data sources, initial analyses examined urban and non-urban crash separately.

The general approach to analyses followed the methods of Åkerstedt et al. (2001[16]). Risk of crash was calculated for each hour of the day with reference to the 10-11am time bin (the relative risk minima), and expressed as an odds ratio (OR) with 95% confidence intervals (CI). The confidence intervals were calculated from the standard error of the logOR, then antilogged by conventional methodology[38]. The OR provides a useful index of the association between binary outcome variables (i.e. crash and no-crash), and the application of the OR to medical statistics has been well described by Bland and Altman [38]. The OR value is typically very similar to that for relative risk[4], but with overestimation of risk if events are common. Crashes are rare events when compared to traffic volume, and the OR is likely to provide a robust estimate of risk. The odds in this study are firstly the ratio between traffic volumes at each hour over the volume at 10-11am (exposure), and secondly the ratio between crash numbers at each hour over the crash numbers at 10-11am (cases) [39]. When the OR = 1 there is no relationship between the variables (e.g. no increased risk of crash at night), and 95% CI's that do not include 1 suggest significantly increased risk of crash.These analyses were carried out for each crash severity category by age and gender sub-groups. In contrast to Åkerstedt et al. [16], risk was not adjusted for age-specific exposure (reliable age exposure data was not available), and was not adjusted for gender differences in exposure.

---

[3] https://www.webcrash.transport.qld.gov.au/webcrash2
[4] Relative risk is related to the difference in outcomes with and without a risk factor, and odds ratio is related to the difference in the presence of a risk factor in those with and without a condition.

Results

The distribution of the 108,010 crashes across the day indicated two peaks (approximately 9am and 5pm) corresponding to commuter traffic volume peaks (Figure 1a & b). The shapes of both the traffic volume and crash frequency curves are substantially similar for the two regions. Mean sunset time in Brisbane is 5.51pm (5.00 – 6.48pm range), and mean sunrise time is 5.44am (4.45-6.39am range). Of the 108,010 total recorded road crashes (urban and non-urban), 81,690 occurred during daylight hours and 26,320 occurred during the night. There was no difference between the urban and non-urban regions regarding the proportion of day and night crashes (χ^2= 0.49, df=1, p=0.48). There was also no difference between the urban and non-urban regions regarding the proportion of traffic volumes occurring during the day and the night (χ^2=0.21, df=1, p=0.64). Approximately 25% of the total daily traffic volume occurred during the night. The frequency of crash by severity category is noted in Table 1 and Table 2 for each region. Between 0.3 and 1% of all crashes were fatal, and approximately 36% of all crashes involved 17-24 year old drivers. In contrast, young drivers comprise approximately 15% of all license holders.
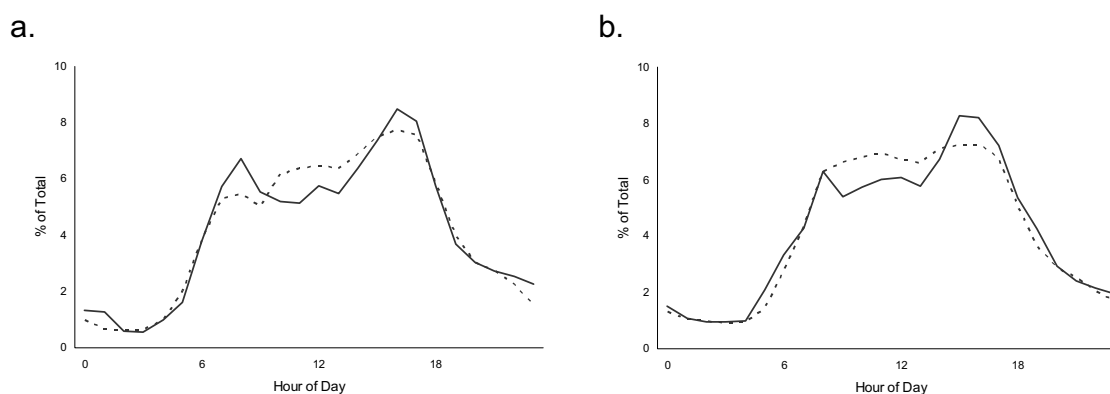
a.

b.

Figure 1. Exposure and serious crash frequency (crashes resulting in fatality or hospitalization). The frequency of serious crash is represented by the dark line. Traffic volume is represented by the dashed line. Data is for each hour of the day (as a proportion of daily total). **a** =urban region data, **b** =non-urban region data.

When total crash prevalence was adjusted for traffic volume, relative risk for all crash peaked at 2-3am with secondary peaks at 9-10am and 3-5pm. Minimum relative risk occurred around 10-11am. This minimum was used as the reference time for subsequent time of day analyses (and is consistent with previous analyses[16]). Figure 2 depicts the odds ratios for risk of crash for all ages, collated into 3-hour time bins for each crash severity level (fatal, hospitalization, medical treatment, minor injury and property damage only), relative to 9-11am. Peak risk for fatal crash occurred between 3-5am, with OR=2.88 (95%CI = 2.08-4.00), χ^2=42.33, df=1, p<.0001.

Time of day by age: To allow direct comparison of risk magnitude to that presented in previous reports[16], data for all crashes (in both regions) resulting in fatality or hospitalization were collated into 3-hour time bins across gender. Figure 3 indicates a peak risk for young drivers between midnight and 2am , OR = 2.92 (95% CI = 2.52-3.37), χ^2=228.34, df=1, p<.0001, relative to 9-11am. Increased risk for younger drivers is also seen across the late afternoon and evening hours. In this analysis, the risk for the oldest driver group is decreased in the early morning hours.

Table 1. Crash counts in the Urban region 2001-2006. Crash severity by Age group.

Age	Fatal	Hospital	Medical treatment	Minor injury	Property damage	Total	%
17-24	33	1611	2892	1833	4547	10916	35.3
25-29	9	561	1157	652	1483	3862	12.5
30-39	17	882	1736	1075	1966	5676	18.4
40-49	15	653	1263	805	1475	4211	13.6
50-59	6	527	980	559	1036	3108	10.1
60-74	11	436	630	364	747	2188	7.1
75 +	11	217	240	114	353	935	3.0
Total	102	4887	8898	5402	11607	30896	
%	0.3	15.8	28.8	17.5	37.6		

Table 2. Crash counts in the Non-urban regions. Crash severity by Age group.

| Age	Fatal	Hospital	Medical treatment	Minor injury	Property damage	Total	%
17-24	239	4817	6259	3555	13398	28269	36.7
25-29	66	1436	1995	1137	3678	8312	10.8
30-39	112	2222	3136	1794	5317	12583	16.3
40-49	84	1847	2395	1476	4178	9980	12.9
50-59	87	1526	1827	1039	3028	7509	9.7
60-74	91	1423	1598	886	2970	6968	9.0
75 +	72	838	787	397	1405	3499	4.5
Total	751	14109	17997	10284	33974	77120	
%	1.0	18.3	23.3	13.3	44.1		
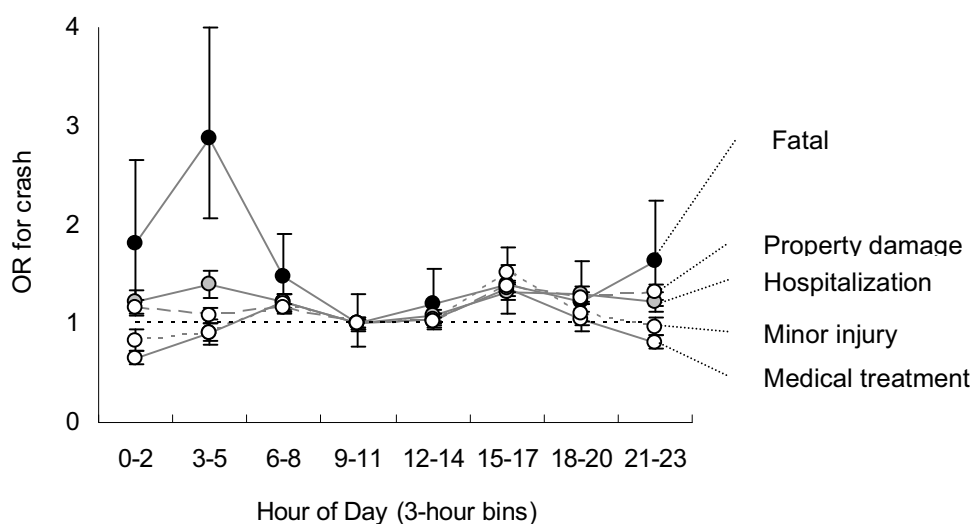
Figure 2. The OR values for risk of crash for each severity category at each time of the day (data for all ages and both genders).   Y-error bars represent the 95% confidence intervals for the OR.
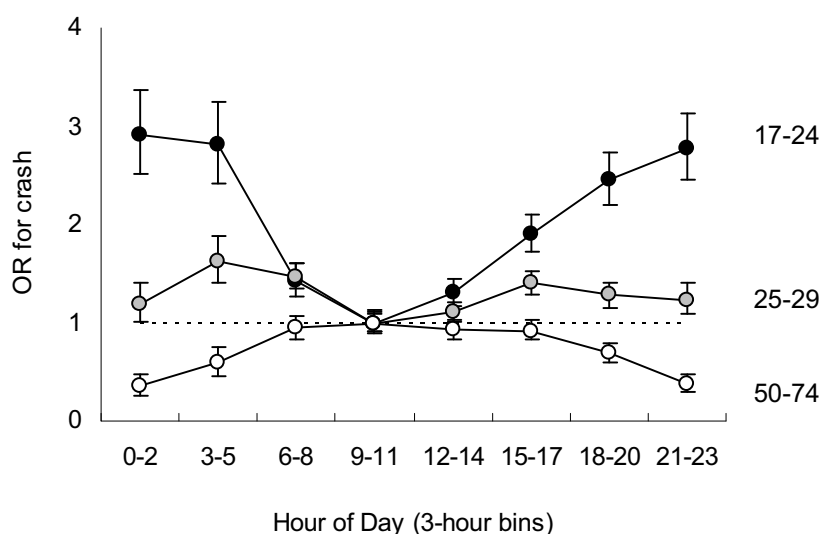
Figure 3. The OR values for risk of crash (Fatal + Hospitalization categories) for 17-24 year olds, 25-49 year olds, and 50-74 year old drivers).   Y-error bars represent the 95% confidence intervals for the OR.

Time of day by gender:
To allow direct comparison of risk magnitude to that presented in previous reports[16], data for crashes resulting in fatality or hospitalization were collated into 3-hour time bins across all age groups. Figure 4 indicates peak risk for males between 3-5am, OR = 2.08 (95% CI = 1.86-2.32), $\chi 2$=173.7, df=1, p<.0001, relative to 9-11am. Increased risk for males is also seen across the afternoon and evening hours. In this analysis, the risk for females is decreased in the early morning hours.
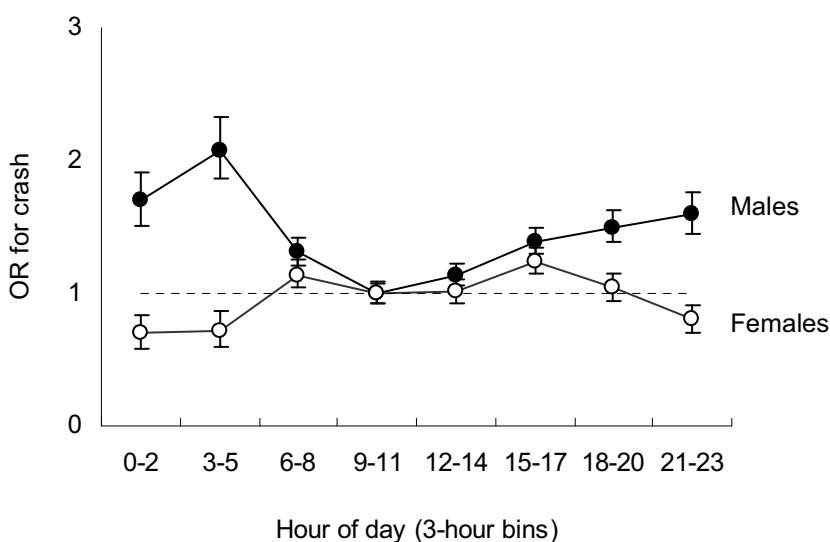

Figure 4. The OR values for risk of crash (Fatal + Hospitalization categories) for males and females across all age groups. Time of day data are in 3-hour bins. Y-error bars represent the 95% confidence intervals for the OR.

Gender effects in risk related to time of day were examined in more detail for the higher risk 17-24 year old driver group. Figure 5 indicates the odds of serious crash (Fatal + Hospitalization categories) at each hour of the day for males, relative to females, in the urban region. The peak OR value, was 11.34 (95%CI=5.35-24.03), χ^2=12.56, df=1, p<.001, and occurred between 2 and 3am. It can be seen in this figures that much of the increased risk of driving at night in young drivers can be attributed to young male drivers, although young female drivers are also at increased risk.
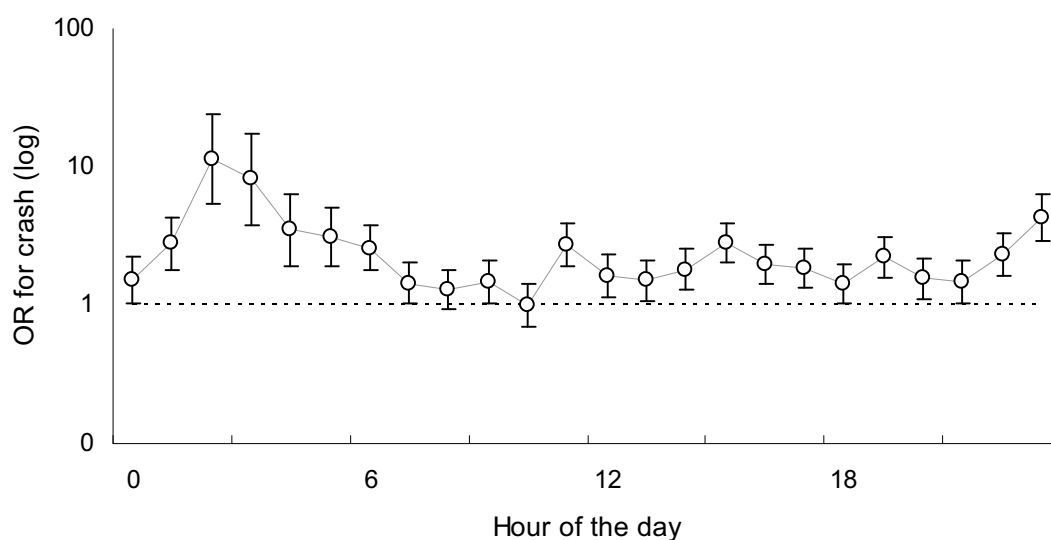

Figure 5. The odds of crash at each hour of the day for 17-24 year old males, relative to females, in the urban region. Y-error bars represent the 95% confidence intervals for the OR. Y-axis is plotted in log scale.

Figure 6 (appendix) indicates the OR for crash at each hour of the day, relative to 10-11am, for each age group and for each crash severity level, for the urban region. Figure 7 (appendix) indicates the same data for the non-urban region. Two general trends are apparent in these composite plots (best seen in Figure 7). First, OR for crash are tend to be higher for the younger age groups across all crash severity categories. Second, time of day peaks are most apparent for more serious crash severity across all age groups. The peak OR values occur between midnight and 5am in younger drivers, and tended to later in the day for older drivers. In fact, the 10am reference point represents a peak risk for the older driver groups (seen as an inversion of the OR plots), with decreased risk at other times of the day. For fatal crashes however, the estimated peak risk occurs during the night hours for all age groups, with the exception of those 75 years and older.

There were too few data for calculation of reliable risk estimates for fatal crash in the urban region. For 17-24 year old drivers in the non-urban region, the OR for fatal crash at 5am was 8.23 (95%CI 3.23-20.94), χ^2=67.4, df=1, p<.001, with a similar peak at 3am. The wide confidence intervals reflect the relatively low incidence in fatal crash. The OR for crash resulting in hospitalization (with higher incidence) for the same age group in the non-urban region was 6.13 (95% CI=3.99-9.43), χ^2=81.16, df=1, p<.001.

Discussion

Over the six-year measurement period, 272 fatalities occurred during the night hours. The results show a late night and early morning increase in crash risk that is most pronounced for serious and fatal crashes, and most pronounced in young drivers (3 times the odds), and in male drivers (over twice the odds). In contrast, older age groups had a lower risk of crash at night than during the morning. The increased risk of crash for fatal crash for 17-24 year old males was over 9 times the odds of that for young females. Both absolute and relative risk estimates therefore support an overrepresentation of males, and particularly young males, in early morning crashes. This increased risk is consistent with previous studies [4, 16].

Non-urban crashes are regarded as a particular issue in Queensland (with a decentralized population), and both urban and non-urban data were examined. It is important to note that the non-urban region contains major population centers, such as Townsville, Rockhamptom and Cairns, in addition to rural and remote geographical area. The general patterns of traffic volume and crash frequency were similar across the day for both sets of data. It is possible that early morning driving was associated with higher risk of fatality, and lower risk of hospitalization, in the non-urban sample (Figure 2 and Figure 3).

The peak risk for young males, when compared to young females, occurred at 2-3am (Figure 4). The confidence intervals for fatal crash in young males were wide, reflecting relatively low numbers of fatalities. The estimate for serious crashes (those resulting in either fatality or hospitalization) for all males was more definite, with a narrow confidence range around increased odds of 2.08 for crashes between 3 and 5am. The acute nighttime peak in risk in younger drivers is not consistent with a direct effect of darkness on driving capacity. The mean sunset and sunrise times across the study period were approximately 6am and 6pm, and in no case did the crash risk peak between 6pm and midnight. The early morning peak is more consistent with international findings that suggest reduced endogenous alertness as the primary contributor to these crashes.   Specifically, circadian and sleep-related models of alertness predict decreased alertness, and decreased cognitive and psychomotor functioning, around or before the circadian temperature minimum. This circadian low point varies between individuals depending on their habitual sleep and wake times, and tends to vary with age. Nevertheless, most data on young adults suggest a circadian nadir around 5am with an earlier nadir in older adults. (e.g. Vitiello et al.[40]). The nighttime crash data may obscure age effects because of this (e.g. older divers may have a nighttime peak at an earlier point, if/when they drive at those times), and variation between individuals will limit the temporal resolution of risk attributable to decreased endogenous alertness.

Folkard [41] has suggested a strong phase relationship between the circadian temperature rhythm and risk in industrial environments, but his data indicates that peak risk occurs some hours prior to the temperature minima. Although Folkard's data [41] was based on full nights of work, rather than intermittent driving, it is consistent with an early morning peak in driving risk associated with circadian arousal mechanisms. Folkard [30] notes an increase in transport crashes after 2-4 hours of driving, which is somewhat independent of circadian-mediated alertness. It is possible that the early morning peak marks the end of a 2-4 hour drive. The issue of time-on-task cannot be directly tested in the current data, as trip information (such as start time and driving duration) is not known. It is possible that night-time trip lengths are greater, but there are no data to support this possibility. To the contrary, Crettenden et al. [42] reported that night time driving trips were of shorter duration and distance than daytime trips by young adults.

This study differed from previous temporal studies by including a range of crash severities. It is recognized that less serious crashes (such as minor injury and property damage crashes) may be underreported, particularly so in rural and remote areas, and particularly if a crash occurs at night. Despite this limitation, clear time-of-day peaks were seen during the night hours across all crash severity categories in younger drivers.

Crashes involving alcohol (i.e. BAC>0) were excluded on the basis that alcohol consumption is dictated by social conventions and availability to most often occur during the night hours. Excluding crashes associated with alcohol therefore provides the best estimate of night-time risk. However, sleepiness is now known to have a very significant potentiating effect on alcohol-related driving impairment [32, 43, 44] . It is therefore likely that nighttime crashes involving alcohol also have a significant contribution from the same time-of-day factors associated with non-alcohol related crashes. BAC recording for crashes resulting in a fatality or hospitalization is reliable. However, the determination that BAC testing is 'not required' means that alcohol

was not assessed directly in those cases, and that it may remain a factor in some proportion of the less serious crashes

A limitation of the current study is the lack of reliable age-adjusted measures of exposure. We have reported previously that young drivers drive very frequently at night, and also drive frequently when they are sleepy (Smith et al. 2005[45]). However, it is not known if young drivers in the current data drove disproportionately more at night than other age groups. The calculation of risk is largely determined by the shape of the exposure curve (traffic volume). As such, specific age and gender data is needed to more accurately estimate relative risk. This data was not available, and is difficult to collect. Two strategies to identify age and gender exposure could included 1) roadside data collection, or 2) quasi-induced exposure methodology based on 'not at fault' driver in nighttime crashes involving more than 1 vehicle [46]. Older data [42] suggests that quantitative exposure does not account for disproportionate crash frequency by young drivers at night. In 1992, Drummond and Yeo [47] calculated crash frequency adjusted for distance travelled and driving experience, in 18-20 year old drivers. Crash (per million miles travelled) still occurred at more than twice the frequency at 3am in this young driver group than in older age groups. There may also be age-dependent effects of driving that are independent of exposure. For example, we have found disproportionate impairment in hazard perception in young adults (in driving simulator studies) when driving in the early hours of the morning, when compared to more experienced drivers (Smith et al. 2007 [48]). That is, sleepiness may impact more on the driving performance of younger drivers than of older drivers. Despite this limitation, both the magnitude and timing of increased risk are consistent with the previous report by Åkerstedt et al. [16], which did correct for age-specific exposure.

The finding of substantially increased risk of crash between 2-3am for young male drivers may help to focus research and policy toward sleepiness as a major factor in nighttime road crash. Current efforts still focus predominantly on darkness *per se*, and from social theories about young driver behavior at night. Crettedden [42] listed a number of social, educational and economic differences between young drivers who drove more at night, and young drivers who drove less at night. However, they provided no statistical tests of the significance or magnitude of these differences. Hutchens et al. [49] used a more powerful multivariate logistic model to test the contribution of a wide range of previously identified risk factors to crash in teenage drivers. They found that the driving alone while drowsy, and being a smoker, were the only significant predictors of crash teenage drivers.

Sleepiness can be prevented, and driving when sleepy can be either avoided or directly addressed. Connor [24] reported an 11-fold increase in fatal crash when acutely sleepy at any time of the day, and 5 times the odds for crash when driving between 2am and 5am. More recent data supports the strong predictive power of an alertness model for crash risk [50]. Empirically focused strategies to detect, prevent and combat sleepiness are likely to provide gains in road safety, and particularly for nighttime road safety in young drivers.

References:

1. Smeed, R.T., Some statistical aspects of road safety research. Journal of the Royal Statistical Society. Series A (General), 1949. 112(1): p. 1-34.
2. Williams, A.F., S.A. Ferguson, and J.T. Shope, Rationale for graduated licensing and the risks it should address. BMJ, 2002. 8(90002): p. 9.
3. Williams, A.F., Nighttime driving and fatal crash involvement of teenagers. 1985. p. 1-5.
4. Doherty, S.T., J.C. Andrey, and C. MacGregor, The situational risks of young drivers: the influence of passengers, time of day and day of week on accident rates. 1998. p. 45-52.
5. Massie, D.L., K.L. Campbell, and A.F. Williams, Traffic accident involvement rates by driver age and gender. 1995. p. 73-87.
6. Mortimer, R.G. and J.C. Fell, Older drivers: their night fatal crash involvement and risk. Accident Analysis and Prevention, 1989. 21(3): p. 273-82.
7. Massie, D.L., K.L. Campbell, and A.F. Williams, Traffic accident involvement rates by driver age and gender. Accid. Anal. Prev. , 1995. 27 (1): p. 73–87.
8. Williams, A.F., Teenage drivers: patterns of risk. Journal of Safety Research, 2003. 34(1): p. 5-15.
9. Owens, D.A. and M. Sivak, Differentiation of Visibility and Alcohol as Contributors to Twilight Road Fatalities. Human Factors, 1996. 38(4).
10. Keall, M.D., W.J. Frith, and T.L. Patterson, The contribution of alcohol to night time crash risk and other risks of night driving. Accident Analysis and Prevention, 2005. 37(5): p. 816-824.
11. Theeuwes, J., J.W.A.M. Alferdinck, and M. Perel, Relation between glare and driving performance. Hum. Factors 2002. 44 (1): p. 95–107.
12. Leibowitz, H.W., D.A. Owens , and R.A. Tyrrell, The assured clear distance ahead rule: implications for night time traffic safety and the law. Accid. Anal. Prev. , 1998. 30 (1): p. 93–99.
13. Bruneau, J.F., D. Morin, and M. Pouliot, Safety of Motorway Lighting. Transportation Research Record, 2001. 1758(-1): p. 1-5.
14. Transport., D.f., Road Casualties Great Britain 2002: Annual Report. 2003, Her Majesty's Stationery Office.: London.
15. Flatley, D., L.A. Reyner, and J.A. Horne, Sleep-related crashes on UK roads during light and darkeness., Transport Canada.
16. Akerstedt, T. and G. Kecklund, Age, gender and early morning highway accidents. Journal of Sleep Research, 2001. 10(2): p. 105-110.
17. Williams, A.F. and D.F. Preusser, Night driving restrictions for youthful drivers: A literature review and commentary. Journal of Public Health Policy, 1997. 18(3): p. 334-345.
18. Stamatiadis, N., S. Jones, and L. Aultman-Hall, Causal Factors for Accidents on Southeastern Low-Volume Rural Roads. Transportation Research Record, 1999. 1652(-1): p. 111-117.
19. Arnedt, J.T., et al., Simulated driving performance following prolonged wakefulness and alcohol consumption: separate and combined contributions to impairment. Journal of Sleep Research, 2000. 9(3): p. 233-241.
20. ATSB, Alcohol and road fatalities, in Monograph 5. 2001, Australian Transport Safety Bureau: Canberra.
21. Summala, H. and T. Mikkola, Fatal Accidents among Car and Truck Drivers: Effects of Fatigue, Age, and Alcohol Consumption. Human Factors, 1994. 36(2): p. 315-326.
22. Horne, J. and L. Reyner, Vehicle accidents related to sleep: a review. Occup Environ Med, 1999. 56(5): p. 289-94.
23. Connor, J., et al., The role of driver sleepiness in car crashes: a systematic review of epidemiological studies. Accident Analysis & Prevention, 2001. 33(1): p. 31-41.
24. Connor, J., et al., Driver sleepiness and risk of serious injury to car occupants: population based case control study. British Medical Journal, 2002. 324(7346): p. 1125.
25. Akerstedt, T., et al., Impaired alertness and performance driving home from the night shift: a driving simulator study. J Sleep Res, 2005. 14(1): p. 17-20.
26. Philip, P., et al., Fatigue, sleepiness, and performance in simulated versus real driving conditions. Sleep, 2005. 28(12): p. 1511-6.
27. Horne, J.A. and L.A. Reyner, Sleep related vehicle accidents. BMJ, 1995. 310(6979): p. 565-7.
28. Borbely, A.A., A two process model of sleep regulation. Hum Neurobiol, 1982. 1(3): p. 195-204.
29. Haworth, N.L. and G. Rechnitzer, Description of fatal crashes involving various causal variables. Technical Report CR 119. 1993, Federal Office of Road Safety.: Canberra: .
30. Folkard, S., Black times: temporal determinants of transport safety. Accident Analysis and Prevention, 1997. 29(4): p. 417-30.

2008 Australasian Road Safety Research, Policing and Education Conference
November 2008, Adelaide, South Australia
This paper has been peer-reviewed

633

31.   Lenne, M.G., T.J. Triggs, and J.R. Redman, Time of day variations in driving performance. Accid Anal Prev, 1997. 29(4): p. 431-7.

32.   Horne, J.A., L.A. Reyner, and P.R. Barrett, Driving impairment due to sleepiness is exacerbated by low alcohol intake. British Medical Journal, 2003. 60(9): p. 689.

33.   Horne, J. and L. Reyner, Sleep-related vehicle accidents: some guides for road safety policies. Transportation Research Part F: Psychology and behaviour, 2001. 4(1): p. 63-74.

34.   Philip, P., Fatigue, alcohol, and serious road crashes in France: factorial study of national data. BMJ, 2001. 322(7290): p. 829-830.

35.   McConnell, C.F., K.M. Bretz, and W.O. Dwyer, Falling Asleep at the Wheel: A Close Look at 1,269 Fatal and Serious Injury-Producing Crashes. Behavioural Sleep Medicine, 2003. 1(3): p. 171-183.

36.   Kim, K.E. and E.Y. Yamashita, Asleep at the Wheel: Spatial and Temporal Patterns of Fatigue-Related Crashes in Honolulu. Transportation Research Part F: Psychology and behaviour, 2001. 1779(-1): p. 46-53.

37.   RTA, N.S.W. Traffic Volume Data. 2008 [cited 2008 10/3/08]; Available from: http://www.rta.nsw.gov.au/publicationsstatisticsforms/aadtdata/index.html?plid=trafficvolume.

38.   Bland, J.M., Statistics Notes: The odds ratio. British Medical Journal, 2000. 320(7247): p. 1468-1468.

39.   Altman, D.G., J.J. Deeks, and D.L. Sackett, Odds ratios should be avoided when events are common British Medical Journal, 1998. 317: p. 1318.

40.   Vitiello, M.V., et al., Circadian temperature rhythms in young adult and aged men. Neurobiology of Ageing, 1986. 7(2): p. 97-100.

41.   Folkard, S., D.A. Lombardi, and M.B. Spencer, Estimating the Circadian Rhythm in the Risk of Occupational Injuries and Accidents. Chronobiology International, 2006. 23(6): p. 1181-1192.

42.   Crettenden, A., E. Yeo, and A.E. Drummond, Qualitative Dimensions of Young Driver Driving Exposure as a Function of Time of Day. 1994, Federal Office of Road Safety: Canberra. p. 125.

43.   Koelega, H.S., Alcohol and vigilance performance: a review. Psychopharmacology, 1995. 118(3): p. 233-249.

44.   Barrett, P.R., J.A. Horne, and L.A. Reyner, Sleepiness combined with low alcohol intake in women drivers: greater impairment but better perception than men? Sleep, 2004. 27(6): p. 1057-62.

45.   Smith, S., M. Carrington, and J. Trinder, Subjective and predicted sleepiness while driving in young adults. Accid Anal Prev, 2005. 37(6): p. 1066-73.

46.   Rice, T.M., C. Peek-Asa, and J.F. Kraus, Nighttime driving, passenger transport, and injury crash rates of young drivers. Injury Prevention, 2003. 9: p. 245-250.

47.   Drummond, A.E. and E.-Y. Yeo, The risk of driver crash involvement as a function of driver age. 1992, Monash University Accident Research Centre: Melbourne.

48.   Smith, S.S., et al., Sleepiness and hazard perception while driving in experienced and inexperienced drivers. Sleep and Biological Rhythms., 2007. 5(S1): p. A104.

49.   Hutchens, L., et al., Teen driver crash risk and associations with smoking and drowsy driving. Accid. Anal. Prev., 2008. 40: p. 869-876.

50.   Akerstedt, T., et al., Predicting road crashes from a mathematical model of alertness regualtion - The Sleep/Wake Predictor. Accid. Anal. Prev., 2008. in press.

51.   Tufte, E.R., The visual display of quantitative information. 1986: Graphics Press Cheshire, CT, USA.
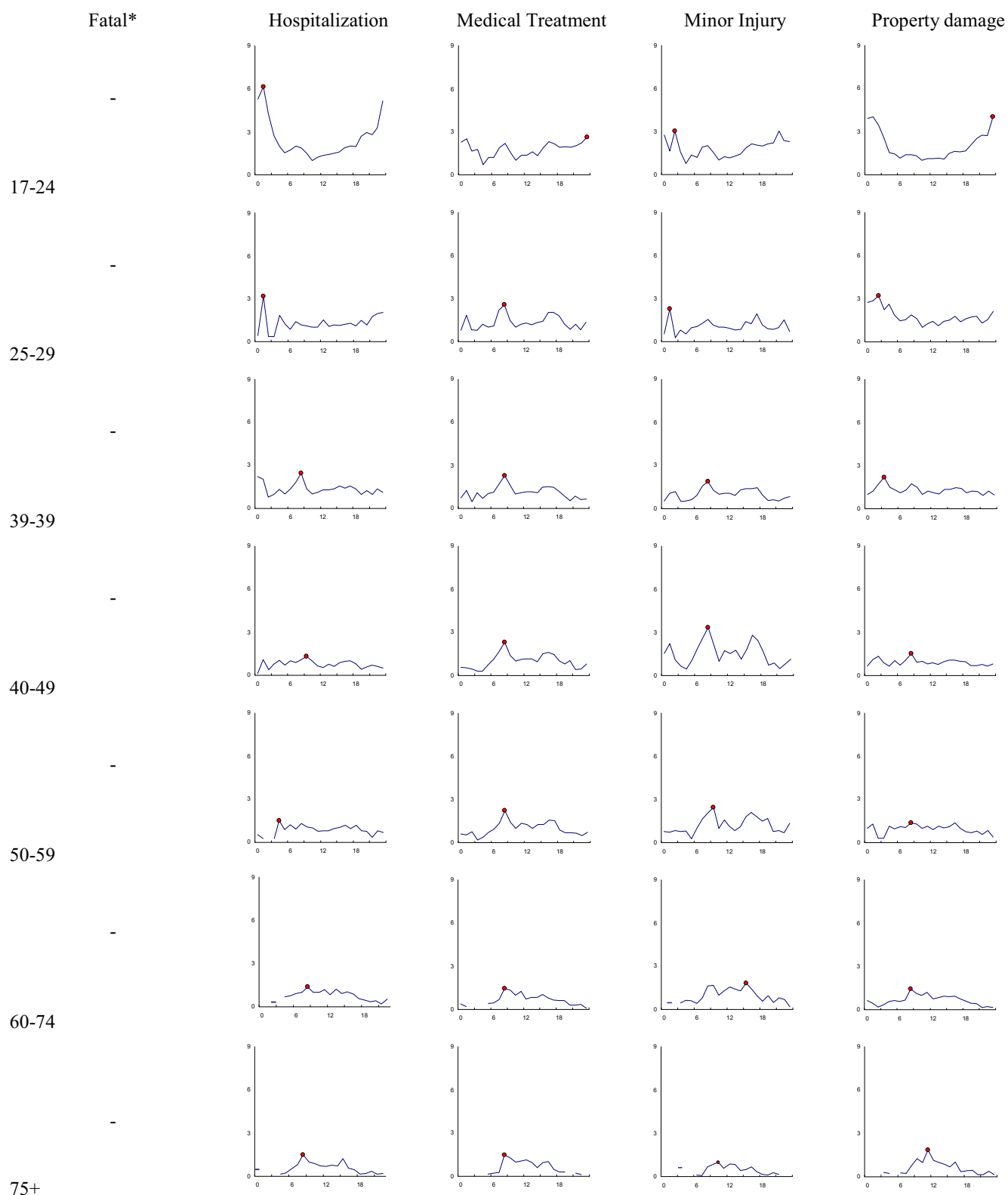
Figure 6. Urban region risk of crash by age group and crash severity. Odds ratio for risk relative to 10-11am plotted on the Y-axis for each hour of the day on the X-axis. Red dot indicates OR maximum. For principle of small multiples see Visual Display of Quantitative Information [51]. *insufficient data for fatal crash in this region.
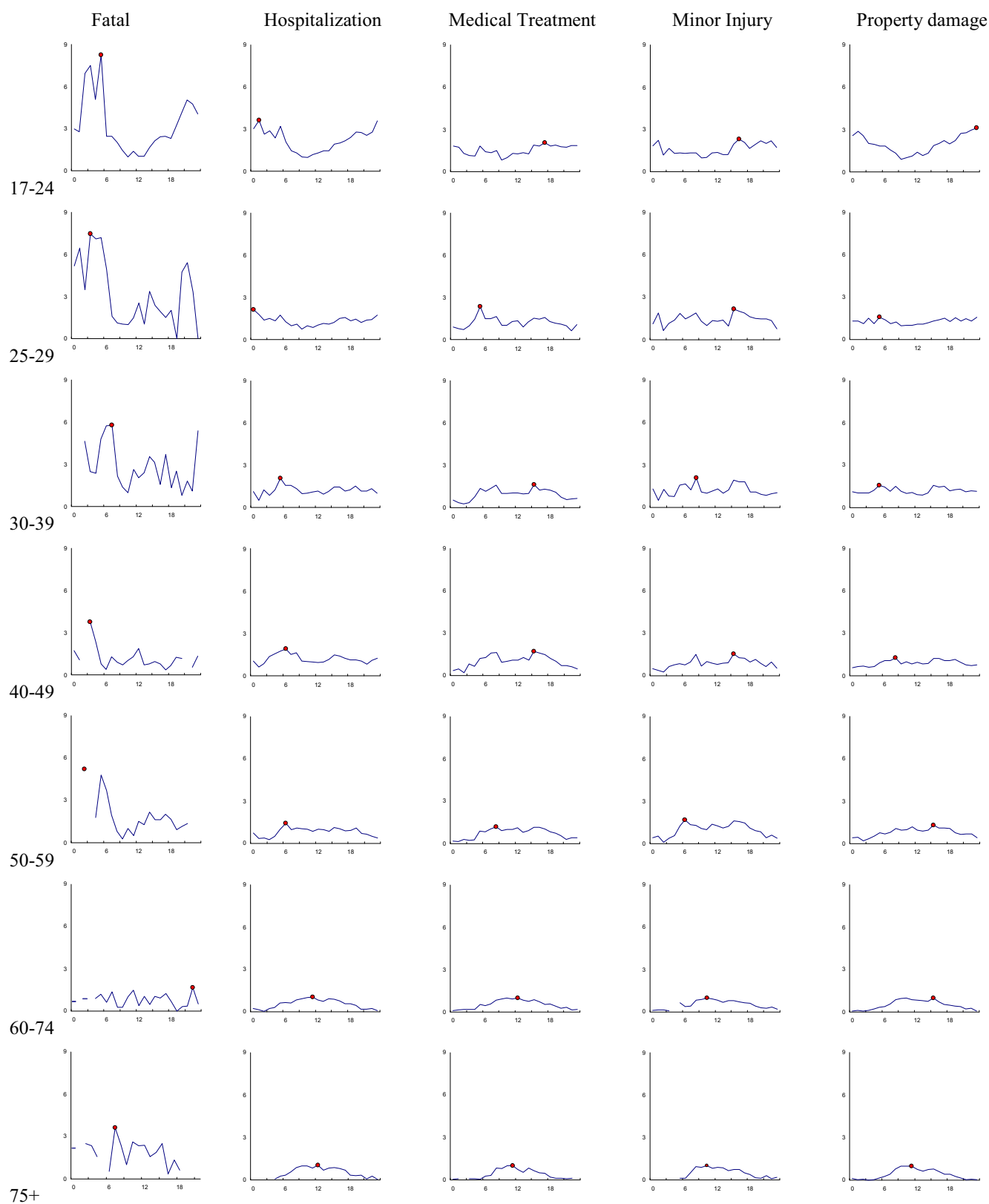
Figure 7. Non-urban zone risk of crash by age group and crash severity. Odds ratio for risk relative to 10 11am plotted on the Y-axis for each hour of the day on the X-axis. Red dot indicates OR maximum.