Exploring Driver Behaviour under Conditions of Darkness: Shedding light on the night time traffic death toll

by

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December 2018

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Abstract

Road traffic crashes are a global public health concern and the leading cause of deaths and injuries. While it is possible to be involved in a road crash at any given time within the traffic environment, previous research studies have shown that the burden of road-traffic injuries is disproportionately borne by hours of the day during which the lowest proportion of traffic is typically present, i.e. night time. In South Africa, 58% of traffic deaths occur during the hours of darkness in South Africa, and the risk of being in a fatal crash is 4-5 times higher at night time than daytime. The purpose of this study was to explore driver performance and behaviour under night time conditions in order gain insight into traffic crash patterns and driving behaviour at night time. This was accomplished by analysing crash and fatality data over a period of 10 years to examine the characteristics of night time crashes, analysing driver videos to assess driver performance at night time (in terms of speed choice, intersection behaviour and compliance with traffic rules) and examining the beliefs and perceptions of drivers that underpin and govern their behaviour at night by means of a survey.

The results from the crash and fatality datasets indicate that traffic fatalities are higher at night time, head/rear end crashes and crashes with fixed/other objects are predominant at night, pedestrians constitute the largest proportion of fatalities and traffic fatalities are higher at night for young male drivers. The results from the driving videos show that at night, drivers exceed the speed limit or adopt a speed that closely approximates the speed limit, use enhancements in street lighting to increase speed and adopt similar scanning patterns at night time as during the daytime. The results from the surveys indicate that drivers generally rate their driving ability at night more positively, are more likely to adopt higher speeds and contravene traffic rules at night, are likely to experience highway hypnosis and struggle with detecting pedestrians and estimating the speed of moving vehicles. The findings from this study can aid in accounting for the high number of traffic fatalities at night, assist in constructing relevant and meaningful interventions to reduce the number of traffic deaths at night and help engineers and designers to develop roadway facilities that accommodate drivers' needs and limitations at night.

Opsomming

Padongelukke is ŉ wêreldwye publieke gesondheid bekommernis en die toonaangewende oorsaak van dood en beserings. Alhoewel dit moontlik is om op enige oomblik in ŉ padongeluk betrokke te wees in die verkeeromgewing, vorige navorsingstudies het gewys dat die las van padongelukke oneweredig gedra word deur ure van die dag waartydens die laagste proporsie verkeer tipies teenwoordig is, d.w.s. tydens die nag. In Suid-Afrika vind 58% van verkeerdode tydens die ure van donkerheid plaas en die risiko om in ŉ noodlottige botsing te wees is 4-5 keer hoër tydens die nag as in die dag. Die doel van hierdie studie was om bestuurder optrede en gedrag onder nagkondisies te verken om sodoende insig na verkeerbotsingpatrone en bestuurder gedrag gedurende die nag te verkry. Dit is bereik deur data oor botsings en noodlottighede oor ŉ tydperk van 10 jaar te analiseer en die eienskappe van nag-ongelukke te ondersoek, bestuurvideo's te analiseer om bestuurder optrede gedurende die nag (in terme van spoedkeuse, interseksie gedrag en nakoming van verkeerswette) te evalueer en om die oortuigings en persepsies van bestuurders wat hulle gedrag gedurende die nag regeer, te ondersoek met behulp van ŉ opname.

Die resultate van die datastelle van botsings en noodlottighede dui aan dat verkeerdode meer is gedurende die nag, dat kop/agterkant botsings en botsings met vaste/ander objekte oorheersend gedurende die nag is, dat voetgangers die grootste proporsie van noodlottighede opmaak en dat verkeerdode hoër gedurende die nag is vir jong mans. Die resultate van die bestuurvideo's wys dat, gedurende die nag, bestuurders die spoedgrens oorskry of ŉ spoed baie naby aan die spoedgrens aanneem, verbeteringe in straatbeligting gebruik om spoed te vermeerder en soortgelyke kykpatrone gedurende die nag as gedurende die dag aanneem. Die resultate van die opnames toon aan dat bestuurders oor die algemeen hul bestuursvermoë meer positief gradeer, dat hulle meer waarskynlik is om hoër spoed aan te neem, dat hulle verkeerswette oortree gedurende die nag, dat hulle waarskynlik snelweg hipnose sal ondervind en dat hulle sukkel om voetgangers te sien of om die spoed van bewegende voertuie te skat. Die bevindinge van hierdie studie kan help om te reken vir die hoë getal verkeerdode gedurende die nag, kan help met die konstruksie van relevante en betekenisvolle ingrypings om die getal verkeerdode gedurende die nag te verminder en om ingenieurs en ontwerpers te help om padfasiliteite te ontwerp wat bestuurders se benodighede en beperkings gedurende die nag kan akkommodeer.

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Dedications

Dedicated to my dear mother, Hawa Williams

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Chapter 1: Introduction

1.1 Background

Road traffic crashes are a global public health concern and the leading cause of deaths and injuries. Each year approximately 1.3 million people die as a result of road traffic crashes and 50 million others sustain non-fatal injuries (World Health Organisation, 2015). Despite the high prevalence of road traffic crashes worldwide, large disparities exist between regions, with 95% of fatalities occurring in middle-income and low-income countries which only possess 48% of the world's registered vehicles (World Health Organisation, 2016). In developing countries, the risk of dying from a road traffic injury is 2.7 times higher than in developed countries.

South Africa is characterized by exceptionally high rates of traffic crashes and is regarded as one of the most unsafe countries for road travel. It has one of the worst traffic death records and was ranked 177th out of 182 countries on the road traffic mortality rate, with 27.91 traffic deaths per 100 000 population, compared to the global average of 10 deaths per 100 000 people (World Health Organisation, 2013). Data from the National Injury Mortality Surveillance System (NIMSS) reveal that in 2009 transport-related injuries were the second highest cause of non-natural deaths, accounting for 33.8% of all deaths in this category (Matzopoulos, Prinsloo, Bradshaw, Pillay-van Wyk, Gwebushe, Mathews, Martin, Laubscher, Lombard, Abrahams & Wyk, 2013). According to the Road Traffic Management Corporation (RTMC), in 2017, road traffic crashes were responsible for approximately 14050 deaths and as many as 524 000 people were injured in traffic crashes (Road Traffic Management Corporation, 2017). This amounts to almost 39 fatalities every day and 12.79 fatalities per 10 000 registered motorised vehicles. Road traffic crashes also place an enormous burden on the South African economy. Based on 2015 fatal road traffic crash data, traffic crashes cost the South African economy approximately R142.95 billion (Labuschagne, De Beer, Roux & Venter, 2016). Moreover, the cost to the economy is R5 435 261 per fatal crash, R423 858 per serious injury and R71 352 per slight injury (Labuschagne *et al.*, 2016). The economic burden also extends to communities and society at large since this depletes already scarce resources, impedes economic development and further perpetuates poverty.

While it is possible to be involved in a road crash at any given time within the traffic environment, previous research studies have shown that the burden of road-traffic injuries is disproportionately borne by hours of the day during which the lowest proportion of traffic is typically present, i.e. night time. Several studies have shown disparities between the number of crashes and fatal injuries occurring during darkness and daylight, indicating elevated fatal crash risk during night time. As early as the 1980s Herd, Agent and Rizenbergs (1980) found that crash rates across all types of rural roads were higher at night time compared to day time. Moreover, disparities in injury severity exist between the two light conditions with fatal crashes almost four times higher at night time relative to daytime. Subsequent studies by Massie & Campbell (1993) examined mileage-based crash rates according to light condition. They found that that when crash rates were calculated per mile driven, the night time fatal crash involvement rate for drivers of all ages was 4.6 times higher than the fatal crash involvement rate at daytime. More recently, Plainis, Murray & Pallikaris (2006) reported that the severity of crashes double during night time when compared to daytime and Verghese & Shankar (2007) reported a three-fold increase in the fatality rate at night relative to daytime. In South Africa, a similar trend in night time crash statistics is evident with a significant proportion of road traffic crashes and fatalities occur during hours of darkness. In 2016, approximately 58% of fatal crashes in South Africa occurred generally at night time, which is characterised as the hours between 06:00 PM and 06:00 AM (RTMC, 2016). Of these fatalities, 38% occurred between 06:00 PM – 12:00 AM.

Night time crashes and fatalities constitute a large proportion of crashes in South Africa. Creating a suitable action plan to tackle the road safety crisis therefore necessitates addressing road traffic casualties at night time which in turns implies having a rich and complete understanding of driving performance and behaviour at night.

1.2 Problem statement

Driving is a pervasive part of everyday life and a complex task conducted in a constantly changing environment. Fundamental to the safe and efficient navigation of traffic terrain is the interaction of road users, vehicles and the road environment. Aside from engineering factors such as the construction and maintenance of vehicles and road infrastructure, a large proportion of road injuries and fatalities can be attributed to human error. Drivers face the huge task of operating a vehicle effectively whilst absorbing the large amount of stimuli they are inundated with and managing and coordinating their responses to the traffic environment.

To successfully cope with the driving task, a rich diversity of sensorimotor, cognitive, affective and psychological functions and processes are employed, some of which include meticulous hand-eye coordination, perception, attention, analysing aspects of fellow drivers' actions, constructive affective states such as patience and rule compliance and managing antagonistic interactions from other drivers. In addition to the traffic environment and the mental workload imposed on drivers, changing atmospheric conditions and night time also contribute to the difficulty of driving.

Driving under the best conditions is a challenge as it is. As can be expected then, night time driving presents unique challenges, increased risks and numerous deaths and injuries. This has been reflected in crash statistics which shows that while only a quarter of driving is done at night, more than 50 percent of traffic deaths occur at night (Plainis *et al.*, 2006). In South Africa, this number is even greater. Considering that fewer drivers occupy the roads at night, these statistics are especially staggering. The temporal variation in road traffic fatalities can be attributed to a number of risk factors that increase susceptibility to collisions on the road at night. These factors include decreased visibility, compromised night vision, fatigue, reduction in depth perception, impaired judgment due to substance abuse and a range of other factors relating to voluntary risk-taking by drivers. In addition, many road users underestimate the unique challenges and risks associated with night driving as they believe that there is safety in reduced traffic and consequently do not adjust their driving to deal with the challenges of driving at night.

To date, there are a limited number of scientifically based studies on the characteristics of night time traffic crashes. Within the South African context, aside from the fact that night time accounts for the majority of traffic fatalities, little is known about crashes or driving behaviour during this period. There is thus an apparent information shortfall in the characteristics and patterns of night time crashes which suggests scope for further research on the issue. An in-depth understanding of night time crash characteristics, driver performance at night time (such as speed choice, intersection behaviour and compliance with traffic rules) and the beliefs and perceptions held by drivers that underpin and govern these behavioural patterns at night is therefore crucial.

1.3 Significance of the study

The results of this study can be used to gain insight into traffic crash patterns and driving behaviour at night time which can be used to develop better design guidance for engineers and designers. This knowledge can inform the design of roadway facilities to accommodate driver behaviour as well as their needs and limitations under conditions of darkness. Understanding driving behaviour at night can also be used to develop better policy guidance for other stakeholders in the field of road safety (such as law enforcement) which play a crucial role in addressing the high rates of traffic fatalities occurring at night. Furthermore, understanding drivers' perceptions and beliefs as it relates to night driving can also augment our understanding of the motivations and reasons influencing driver performance on the road at night and this can be useful for enforcement and education efforts that target particular road users. Finally, understanding the characteristics of night time crashes is beneficial in constructing relevant and meaningful interventions to address the high rates of traffic fatalities at night. A need for research on the phenomena of night time traffic crashes and driving behaviour is therefore relevant.

1.4 Delineations of the study

In this study, driver performance and behaviour under conditions of darkness was investigated and naturalistic driving videos were used to provide insight into driving behaviour at night time. Given that the sample of drivers from the naturalistic driving videos only comprises four drivers, the results obtained is not representative of the entire driving population and can therefore not be generalised. Despite the non-representativeness of the sample, the information obtained is still valuable and useful in assessing driver behaviour and interaction with the road environment under night time conditions. Furthermore, the value of the videos is derived from how closely it approximates real-life driving behaviour hence, even though the results are not reliable, it does have high validity compared to other methods of assessing driving behaviour (such as driving simulation, external driving videos and instrumented vehicle tests). It is for these reasons that the driving videos were included in this study. However, when interpreting the results it should be kept in mind that the results are true for the drivers under observation and not necessarily all drivers.

1.5 Aims and objectives

The central aim of this study is to explore driver performance and behaviour under night time conditions. Within this framework, the specific objectives are:

1. To investigate the characteristics of night time traffic crashes and fatalities. Within this objective, the specific aims are as follows:

    - To identify the daily and hourly frequency of traffic crashes and fatalities at night crash type
    - To identify the types of crashes frequently occurring during night time
    - To examine the effect of demographic factors such as gender, age and race on traffic fatalities during night time
    - To identify high risk road users at night time

2. To investigate driver speed choice at night time. Within this objective, the specific aims are as follows:
    - To examine drivers selection of speed on various roads at night
    - To examine the relationship between street lighting and driver speed at night

3. To investigate driver gaze behaviour at various intersections at night time

4. To investigate drivers' behaviour and perceptions of night driving. Within this objective, the specific aims are as follows:
    - To investigate risk perception of driving at night
    - To investigate behaviour and attitudes toward speeding at night
    - To investigate the experience of fatigue at night
    - To investigate the aberrant driving behaviour at night
    - To investigate traffic violations at night
    - To investigate driving task difficulty at night

1.6 Thesis outline

Chapter 1 briefly outlines the background, the research problem and research objectives, delineations of the study and the outline of the thesis. Chapter 2 provides a theoretical basis of the research problem and reviews previous studies relevant to understanding and investigating the research problem. Chapter 3 provides an overview of the research design as well as descriptions of the data sources and methods used to collect; extract and analyse data. Chapter 4 presents the findings of the study. Chapter 5 is a discussion of the main findings of the study. Chapter 6 presents the main conclusions of the study and suggests recommendations to address the research problem.

Chapter 2: Literature Review

2.1 Introduction

This chapter provides a review of previous works relevant to the scope of this study. The literature review chapter provides the existing theory related to the research aims and objectives stated in the first chapter.

Etiological studies of motor vehicle traffic crashes adopt a multi-factor analysis approach to understanding crash occurrence and proposing suitable countermeasures. This stems from the recognition that a road traffic crash results from a combination of elements related to the traffic environment, the road user, the vehicle and the interaction between the factors. Understanding the characteristics of night time crashes necessitates a discussion of human factors, roadway factors and environmental factors as all of these aspects contribute to the prevalence of crashes at night.

The format of the literature is thus broken down into the following sub-chapters which are used to investigate the factors contributing to traffic crashes at night.

1) Night time traffic casualty profile
2) Driver factors affecting night time driving
3) Roadway factors affecting night time driving
4) Vehicle factors affecting night time driving
5) Biological factors affecting night time driving
6) Visual factors affecting night time driving
7) Speed behaviour at night
8) Pedestrian detection at night

2.2 Night time traffic casualty profile

2.2.1 Global context

Night driving is one of the most hazardous activities of daily life. Many studies have shown that driving at night is more risky in terms of crash involvement per distance travelled than during the day. Research as early as 1980 by Herd, Agent & Rizenbergs (1980) report that the severity of crashes was higher on two-lane and four-lane freeways in urban areas during night time compared to daytime. Injury-type crashes were also reported to have increased under conditions of darkness, with the proportion of fatal crashes almost four times higher at night time relative to daytime. Subsequent studies by Massie & Campbell (1993) examined mileage-based crash rates according to light condition. These authors reported that when crash rates were calculated per mile driven, the night time fatal crash involvement rate for drivers of all ages was 4.6 times higher than the fatal crash involvement rate at daytime. More recently, similar results were obtained by Plainis, Murray & Pallikaris (2006) who reported that the severity of crashes double during night time when compared to daytime and by Verghese & Shankar (2007) who reported a three-fold increase in the fatality rate at night relative to daytime. The most recent findings on night time traffic rates are reported by the National Safety Council (2015), who reported that the fatality rate at night is two to four times higher than the daytime rate in the US, when adjusted for mileage.

Night driving is a critical safety issue specifically because the occurrence of fatal crashes at night time is disproportionate to the volume of traffic at night. Whilst most jurisdictions have high crash and fatality rates at night and more than half of all fatal crashes occur during the hours of darkness, only 15%-20% of traffic is operating on the road at this time (Massie, Campbell, & Williams, 1995; Sullivan & Flannagan, 2002).

Drivers are not the only group at risk. Pedestrians also face elevated risk at night time and are three to seven times more likely to be involved in a fatal crash during hours of darkness (Sullivan & Flannagan, 2002). This problem is aggravated in developing countries where pedestrians constitute a higher proportion of the traffic population and interact more frequently with vehicular traffic (Rumar, 2001).

2.2.2 South African context

Traffic fatalities at night time constitute the highest proportion of fatal crashes in South Africa. The percentage of fatal crashes per time of day for the year 2016, in South Africa is depicted in Figure 2-1.

Figure 2-1: Percentage contribution of fatal crashes per time of day in 2016

Source: Road Traffic Management Corporation (2016)

Overall, 58% of fatal crashes occur during the night time period (06:00 PM – 06:00 AM) and 42% of fatal crashes occur during the daytime period (06:00 AM – 06:00 PM). The majority of night time crashes (38%) occurred between the start of the night time period and midnight (18:00-24:00).

In terms of particular hours of vulnerability, most traffic crashes occurred during the following hours of the night time period:

- From 17:00 to 18:00- **6.1%**
- From 18:00 to 19:00- **6.1%**
- From 19:00 to 20:00- **8.2%**
- From 20:00 to 21:00- **7.9%**
- From 21:00 to 22:00- **6.4%**

From these results, it is evident that most fatal crashes occurred during hours of dark on South African roads. Apart from these results, no other data or studies on night time traffic crashes or fatalities are available.

2.3 Driver factors affecting night time driving

While all drivers face risks, there are individual factors that make particular groups of drivers more vulnerable and predisposed to experiencing vehicle crashes and injuries in the traffic environment at night. These risk factors are discussed below.

2.3.1 Age-related effects

The risk of crash involvement varies as a function of driver age (Dingus, Guo, Lee, Antin, Perez, Buchanan-King & Hankey, 2016; Drummond & Yeo, 1992). While night time driving poses a hazard to drivers of all ages, research (Bates et al., 2014; Ryan et al., 1998; Swedler et al., 2012; Williams, 1985) has shown that night time driving is associated with higher crash occurrence among young drivers (16-25 years old).

Earlier studies on the risk of driving at night per distance travelled by Mortimer and Fell (1989) demonstrated that the frequency of fatal crash involvement was higher among young drivers (16-24), followed by older drivers (64 years and older) and middle-aged drivers (25-64). Massie, Campbell and Williams (1995) confirmed these findings by reporting a U-shaped curve between the incidence and number of fatal motor vehicle crashes and driver age, signifying that younger and older drivers have a higher risk of being involved in fatal crashes at night time. In Canada, Zhang et al. (1998) analysed traffic crash data which included time of occurrence, crash type and configuration, light conditions as well as environmental and roadway conditions between 1984 and 1993 to detect patterns between the occurrence of fatal crashes and driver age. The findings of their study indicate that there are differences in risk factors by age group, most notably; that young drivers (16-24 years old) experience the highest risk of being involved in a fatal crash followed by elderly drivers (64 years and older) and middle-aged drivers (25-64).

In comparison with the middle-aged driver group (selected as the referent group due to the U-shaped distribution of crash rate by age), young drivers were also found to be particularly vulnerable on weekends (60%), between the hours of 08:00 PM and 07:59 AM (55%) and during the summer season (33%). In contrast to young drivers, fatalities for middle-aged drivers peaked during weekdays (51%), between 08:00 AM and 07:59 PM (61%) and during the summer season (28%). Elderly drivers risk was elevated on weekdays (51%) and during hours of daylight (77%). Although, daytime is associated with a higher crash mortality rate for both middle-aged and elderly drivers, it should be accentuated that middle-age drivers (39%) are considerably more likely to be involved in a fatal crash at night compared to older drivers (23%) (Zhang et al., 1998). Similar results were obtained by Mortimer & Fell (1989) in their study on fatal crash involvement at night across driver age groups. The fatal crash involvement rate of drivers aged 65 years and older was 34.1, for drivers aged 25-64 years old it was 17.3 and for the youngest group of drivers aged 16-24 years old the rate was 64.3.

When analysing particular hours of vulnerability at night across age groups, it was noted that for elderly drivers (77%) as well as middle-aged drivers (61%) the majority of fatal crashes occurred between the hours of 08:00 AM and 08:00 PM compared to young drivers (45%), indicating that risk is greater between daytime and dusk for these road users. For elderly drivers the risk is more pronounced between 08:00 Am and 04:00 PM and the increase in risk is nearly twofold between noon and 04:00 PM. For middle-aged drivers, the highest number of fatalities (25%) was recorded between 04:00 PM and 07:59 PM and the time period at night that resulted in greater numbers of fatalities is between 08:00 PM and midnight (17%). Conversely, the most dangerous time periods for young drivers, however, were recorded between 08:00 PM and 08:00 AM and the increase in risk is more than twofold between midnight and 04:00 AM, indicating that young drivers experience the greatest risk during darkness in terms of age-specific distributions.

A study conducted in Melbourne in 1988, analysed risk estimates by driver age per distance travelled and reported that young drivers (18-25 years old) demonstrated the highest crash involvement risk followed by older drivers (60 years and older) (Drummond & Yeo, 1992). When night time crashes were analysed for the same data set, drivers of all ages demonstrated elevated risk at night time driving compared to day time. Figure 2-2 shows the risk estimates at day and night time according to driver age.

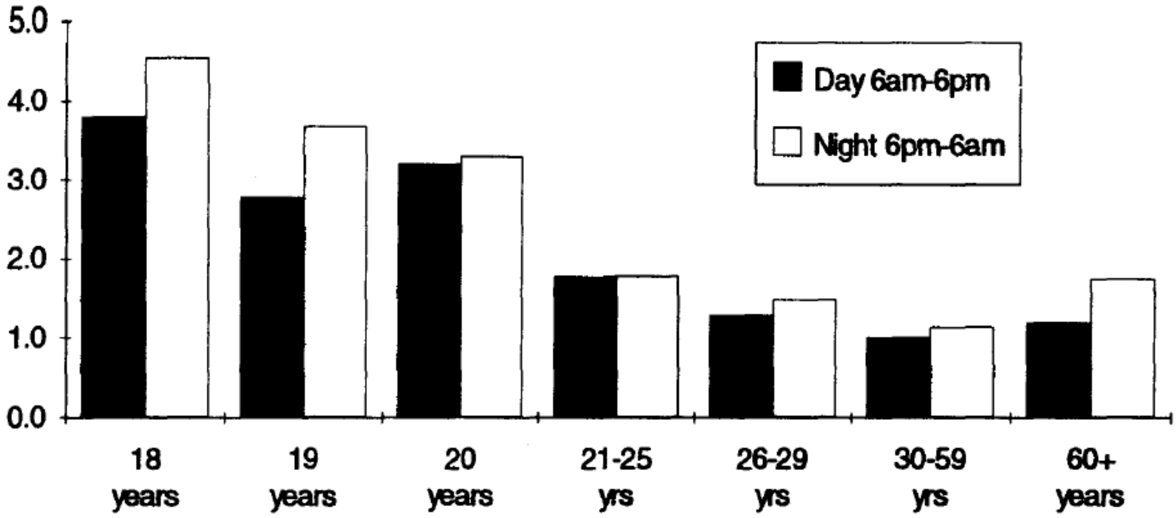


Figure 2-2: Risk estimates- day vs night time by age group per 1 million km travelled

Source: Drummond & Yeo (1992)

According to Figure 2-2, young drivers, however, demonstrated increased risk compared to all the other age groups, followed by older drivers (Drummond & Yeo, 1992). In particular, the risk of being in a crash at night was twice as high for younger drivers than middle-aged drivers and older drivers.

Additional analysis on crash risk was provided by analysing risk estimates according to time of day. The results are displayed in Figure 2-3. The general period of night time (06:00 AM - 06:00 PM) was broken down into single hours of the night to establish which periods of the night are associated with higher levels of risk. According to the data displayed in Figure 2-3, the most dangerous times to drive for all age groups are the early morning period (post-midnight between 01:00 AM and 03:00 AM) followed by the late night period (till midnight between 07:00 PM and 11:00 PM). Compared to the middle-aged driver group, younger drivers showed pronounced risk in the late night period and early morning period. This time period is markedly dangerous for drivers in the 18-20 year old age group.

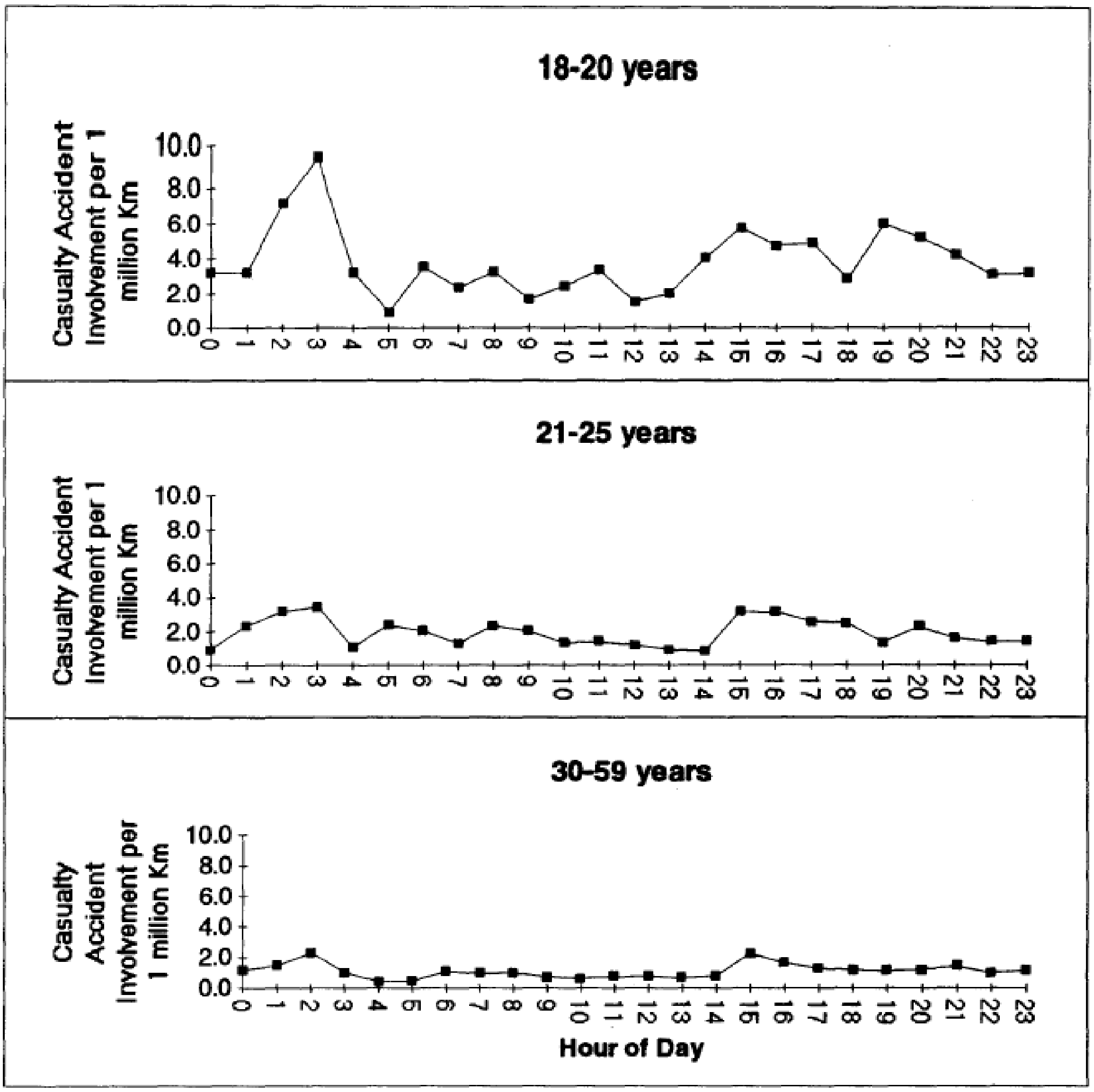


Figure 2-3: Risk estimates by hour of day

Source: Drummond & Yeo (1992)

These results have been affirmed by Rice et al. (2003) who investigated the relationship between night time driving among 16-17 year old passenger vehicle drivers prior to the implementation of a graduated licensing system. Using an induced exposure technique which is based on the premise that non-culpable drivers represent the total population in question and that therefore, non-culpable driver/vehicle data can be compared with that of the group of drivers of interest and can be used as an exposure metric, the findings derived from this study reveal that night time driving is associated with a higher level of risk than daytime driving and that risk is elevated with advancing night time hours but especially when driving between 10 Pm and mid-night (Rice *et al.*, 2003).

2.3.2 Gender-related effects

Research has consistently shown that male drivers face considerably more risk of being involved in a traffic crash than female drivers (Elander, 1993; Swedler et al., 2012; Williams & Shabanova, 2003). In the South African context, the percentage distribution of fatalities per gender is even more staggering with males accounting for 78% of total fatal crashes and females accounting for only 22% of total fatal crashes (Road Traffic Management Corporation, 2016). While night time driving is strongly associated with a greater risk of accident involvement for both young males and females, crash involvement and fatality rates are significantly higher for male than female drivers at night. Swedler et al. (2012) compared gender and age trends among adolescent drivers in fatal crashes. Crashes at night time increased overall for both male and females, however male driver’s crash involvement was higher than females (41% vs. 36%).

Mortimer and Fell (1989) compared the rate of involvement in fatal crashes by gender and time of day for drivers of all ages. According to their results displayed in Table 2-1 and Table 2-2, female rates of fatal crashes were generally and significantly lower compared to male rates. The rate of involvement in fatal crashes for males was almost three times higher than that for females during hours of darkness (6PM-6AM). Even though all drivers showed greater rates of crash involvement at night time across age and gender groups, young males had a relatively high rate of involvement and older females had a relatively low fatal crash involvement rate at night compared to their respective age group counterparts. The highest rate for male and female drivers of all ages was during the midnight to 6 AM period followed by the 6 PM to midnight period, with male drivers dominating crash involvement rates during these periods. This is consistent with findings by Zhang et al. (1998) who observed that young drivers risk of crash at night is substantially elevated between midnight and 4 AM. Older male drivers experience pronounced risk at later periods of the night (from midnight to the 6 AM period) but older female drivers reported higher crash rates in the earlier part of the night (from 6 PM- midnight).

The highest rate for both young male and female drivers occurred during the midnight to 6 am period. Similarly, both male and female middle-aged drivers demonstrated greater risk of crash involvement in later period of the night (midnight- 6 AM) followed by the earlier period of the night (6 PM- midnight). However, this trend was not reported among elderly drivers. The most dangerous time period for older female drivers was 6 PM- 12 and for older male drivers it was 12- 6 AM.

Table 2-1: Fatal crash involvement rates of female drivers by age and time of day

Age	**Time**				
	12-6 AM	**6 AM-12**	**12- 6 PM**	**6 PM-12**	**Total fatal crash rates at night (6 PM- 6 AM)**
16-24	23.9	2.4	3.3	6.5	30.4
25-64	6.3	1.3	1.6	3.1	9.4
65 +	4.6	3.2	5.5	7.2	11.8
Total	34.8	6.9	10.4	16.8	

Adapted from: Mortimer & Fell (1989)

Table 2-2: Fatal crash involvement rates of male drivers by age and time of day

Age	Time				
	12-6 AM	6 AM-12	12- 6 PM	6 PM-12	Total fatal crash rates at night (6 PM- 6 AM)
16-24	64.3	5.1	6.5	16.1	80.4
25-64	17.3	2.1	3.4	9.6	26.9
65 +	34.1	6.7	10.7	11.6	45.7
Total	115.7	13.9	20.6	37.3	

Adapted from: Mortimer & Fell (1989)

Subsequent studies have reported higher crash rates among males than females during the hours of darkness (Rice et al., 2003). In terms of gender representation among drivers involved in fatal crashes, eight out of ten drivers involved in crashes across age groups were male, with young drivers demonstrating the highest number of fatalities (81%).

Consistent with previous research findings, Massie, Green, & Campbell (1997) reported that males displayed increased risk compared to their female counterparts in their study on the effect of age, gender time of day and average annual mileage crash involvement rates. While males appeared to have a 55% higher fatal crash involvement rate compared to females, it was observed that women exceeded the rate of involvement in injury crashes compared to men (women had a 26% higher injury involvement rate) for daytime conditions. The authors attribute this disproportionality in injury rates to women's low average annual mileage, which other studies has used as an indicator of current level of driving experience, with increased mileage indicating greater driving experience which presumably translates into lower crash rates (Massie *et al.*, 1997). At night time, however, men and women appeared to have similar injury involvement rates, with men's risk estimated to be between 0.8 and 1.1 times that of women.

2.3.3 Driving experience

The lack of **driving experience** and familiarity with hazards in the road environment also accounts for the heightened risk of youthful morbidity and exacerbates crash risk (Zhang et al., 1998). Young drivers are less likely to anticipate hazardous situations and consequently are more likely to travel with shorter headways, accept narrower gaps in traffic, disobey traffic signals such as run yellow lights, change lanes improperly, exceed the speed limit and not use seat belts compared to their older counterparts (Zhang et al., 1998) and (Jonah, 1986). Although these observations were made under daylight conditions, it is reasonable to extrapolate these findings traffic behaviour at night time as well especially drivers mostly acquire driving experience at night in the absence of adult supervision.

Jonah (1986) draws attention to the fact that the possible causal factors underlying crash risk is nothing intrinsic to youthfulness but rather the roles of exposure to risk of a crash. Young drivers may be overrepresented in traffic accidents due to higher exposure to the risk of a being involved in a crash (i.e. **they tend to drive more**). Rice et al. (2003) affirms this and attributes the vulnerability and high risk of young drivers at night to the fact because they tend to do a larger share of their driving at night compared to their older counterparts. Older drivers may also voluntarily restrict their driving at night because they are cognisant of their limitations and the additional hazards brought on by night driving and traffic (Mortimer & Fell, 1989). Their decreased absence in the road environment at night may also elucidate the higher rates of traffic crashes among younger motorists relative to older drivers.

Furthermore, the high crash rate observed among young drivers may also be due to the **lack of adult driving supervision** at night. In their study on the effects of night time driving and passenger carrying with the rate of motor vehicle crashes, Rice et al. (2003) found that carrying mature adults was more protective than driving alone, carrying male or female teenage passengers, carrying young adults or carrying children. The absence of adult supervision has a positive correlation with higher crash risk. Indeed, the presence of adult supervision resulted in a 70% reduction in the crash rate than when travelling alone.

The discrepancy in the crash occurrence in daytime and night time conditions have motivated the need for night time curfews and graduated licensing systems for younger drivers. These countermeasures restrict night driving or only allow adult supervised driving on the part of teenage drivers and have been found to be effective in reducing crash rates at night (Rice *et al.*, 2003).

2.3.4 Alcohol-related effects

Driving under the influence of alcohol greatly contributes to the frequency and severity of traffic deaths (Shinar, 2017). It is a well-known and well-documented fact that alcohol use is strongly associated with traffic fatalities and crash risk, leads to markedly poorer crash outcomes and has a high probability ending in a fatality (Behnood & Mannering, 2017; Hingson & Winter, 2003; World Health Organisation, 2015). Drink driving is one of the biggest threats to road safety globally not only because of the devastating consequences likely to follow when driving while intoxicated but because it increases the propensity to engage in other high-risk behaviours such as speeding (Bates *et al.*, 2014a) or neglecting to wear a seat belt (Reagan, McClafferty, Berlin & Hankey, 2013).

Several studies have shown that a person's ability to drive is greatly compromised by the presence of alcohol in their bloodstream. The risk of impairment starts at very low levels of alcohol ingestion and rises exponentially with increasing consumption (Casbon et al., 2003; Liu & Fu, 2007; Moskowitz & Robinson, 1988; Shinar, 2017; Zhao et al, 2014). Alcohol is known to have a deleterious effect on the cognitive and neurological functioning and capacity of drivers and even the smallest quantity of alcohol can lead to severe deficiencies in driving behaviour and performance (Liu & Fu, 2007). Alcohol consumption leads to deficiencies in intellectual functioning which affects visuospatial abilities (perceiving the relative location of objects) and higher cognitive functioning (abstract-thinking capabilities needed to organize reason, plan and govern self-directed behaviour) (Casbon *et al.*, 2003).

In their study on changes in driving behaviour and cognitive performance of drivers with different alcohol concentration levels, Liu and Fu (2007) concluded that the cognitive faculties are the first to be impaired by drinking. The performance of mental tasks related to cognitive faculties such as divided attention, short-term memory, logical reasoning and visual perception deteriorated following as breath alcohol concentration levels (BrAC) increased. In particular, driving while intoxicated had a negative impact on vision and perception, with visual ability such as depth perception or following a safe driving distance being severely impaired at BACs of 0.058% and 0.047%, respectively (Liu & Fu, 2007). In addition, information-processing abilities was also severely hindered which is extremely alarming since this relates to the judgement of moving objects and processing of multiple sources of information (Liu and Fu, 2007). These results are supported by Zhao et al. (2014) who reported that alcohol negatively affected a driver's' visual perception, cognitive judgment and motor behaviour and impacted drivers' judgement, attitude, level of caution, reaction time and control at BAC levels as low as 0.05%. In terms of the debilitating effect alcohol has on driving tasks, Zhao et al. (2014) demonstrated using a driving simulator, that driving while intoxicated increases average speed and lane position deviation and that drivers' ability to operate a vehicle safely was reduced at BAC levels of 0.035%. Accuracy in steering wheel control and braking control ability also declines at BACs of 0.06% (Liu & Fu, 2007).

Compared to daytime, alcohol consumption is accelerated during night time and on weekend, and is implicated in three times as many crashes at night time than daytime crashes (Shinar, 2017). In France, Philip et al. (2001) conducted a factorial study of national data on road crashes alcohol related crashes. The results obtained indicate that traffic crashes involving drunk driving were more likely to be fatal during the evening and early morning than during daytime. In the US, the National Highway Traffic Safety Administration (2002) reported that 40% of all traffic fatalities involved alcohol and fatal alcoholic-related crashes were more likely to occur at night than during day time. Based on the number of alcohol-related fatalities shown in Table 2-3, 77% of fatal crashes were caused by the misuse of alcohol and occurred between 6 PM- 6AM, compared with 33% (23 plus 10) of non-alcohol related fatal traffic crashes.

Table 2-3: Traffic crashes by time of day and BAC (in %)

Time of day	BAC (highest blood alcohol concentration of driver/pedestrian involved in crash)				
	0.00% (n = 22,683)	0.01-0.07% (n = 2,129)	0.08%-0.14% (n = 4,204)	0.15% + (n = 9,293)	0.01% + (n = 15,626)
6 PM-midnight	23	38	38	41	40
Midnight-6 AM	10	29	37	39	37
6 AM- noon	28	11	8	6	7
Noon- 6 PM	39	21	16	13	15

Source: NHTSA (2002)

While anyone who consumes alcohol is at risk, the prevalence of young drivers in fatal crashes peak at night and on week-ends (Zhang et al., 1998) and drink and driving is most prevalent among these drivers. It has also been reported that the overall impact of alcohol on driver risk decreases with increasing age, with male young drivers demonstrating higher crash risk when driving on weekend nights (Keall, Frith & Patterson, 2005). Investigating the association between night time driving and injury crash rates of young drivers, Rice et al. (2003) observed that drivers were 40 times more likely to be in a severe or fatal crash following alcohol consumption and that the rate of crashes increased with advancing night hours. Alcohol consumption which is increased at night time and on weekends may also be responsible for the high number of crashes observed during these peak times and among this high risk group. This can be attributed to the nature of the greater social activity of youth during these times that also creates opportunities for driving while impaired which over time increases the frequency of drink driving (Jonah, 1986).

Even though drink driving is not inherently a night time risk factor, the consumption of alcohol prior to driving occurs predominantly at night. The effect of this behaviour is exacerbated by the effects of fatigue (which is also more prevalent at this time of the day) and reduced visibility. Philip et al. (2001) examined the combination of fatigue and alcohol on road crashes and reported that the presence of both these factors resulted in a greater risk of road crashes resulting in fatalities or serious injury. This is attributed to the fact that alcohol induces sleepiness and BACs as low as 0.01 percent increase susceptibility to fatigue which results in poor performance on the road (Philip et al., 2001).

2.4 Roadway factors affecting night time driving

2.4.1 Roadway lighting

The driving task entails extracting information from the road environment and using this knowledge to make judgements, determine an appropriate course of action and manoeuvre the vehicle accordingly. By enhancing the visibility of the road environment, road lighting plays a major role in enabling drivers' to extract information, make decisions, respond to hazards and adjust driving behaviour accordingly. Road lighting plays a major role in the frequency and severity of traffic crashes and fatalities at night time and is known to have tremendous crash-reducing effects for drivers (Beyer & Ker, 2009a) and particularly, for pedestrians at night (Wanvik, 2009a). It has often been recommended as an economical crash countermeasure to prevent road traffic crashes at night, especially in low and middle-income countries.

The effects of lighting on traffic safety at night have been extensively studied. Following the installation of street lighting, Wanvik (2009) reported that crashes were reduced by up to 50%, in Netherlands while Oya, Ando & Kanoshima (2002) reported a 43% decrease in the number of traffic crashes in Japan at night time. The effects of road lighting are also known to have a larger impact on the severity of crashes. Crabb & Crinson (2008) investigated the proportion of crashes that resulted in fatal or severe injuries on roads with and without street lighting. The results are displayed in Figure 2-4 and indicate that in areas without street lighting, the severity of crashes were higher.

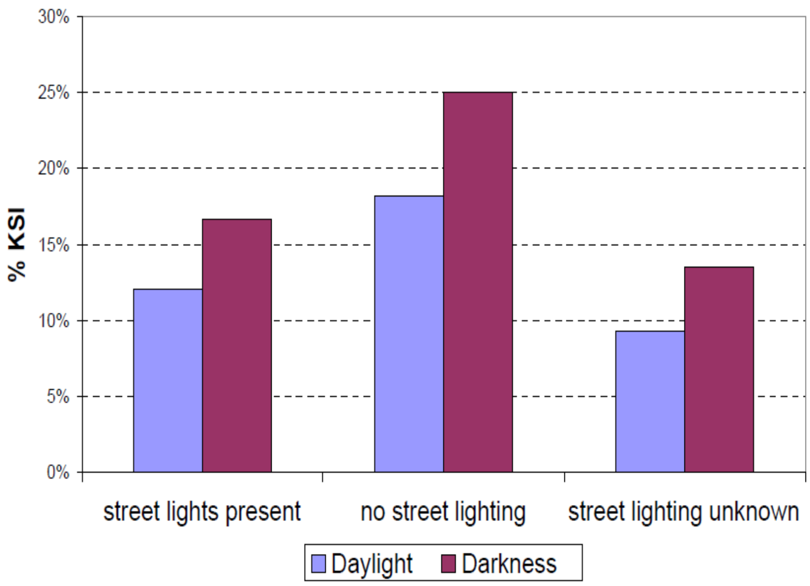


Figure 2-4: Severity ratio (%killed and seriously injured) by lighting condition

Source: Crabb & Crinson (2008)

Furthermore, Plainis *et al.* (2006) reported than on motorways the higher frequency of fatal crashes occur on roads without street lighting (4.3%) compared to roads with street lighting (2.6%). On built-up roads, fatalities were also higher on roads without street lighting (1.9%) compared to roads with street lighting (1.3%).

Road lighting has a bigger crash-reducing effect for pedestrians compared to vehicle occupants. In terms of overall lighting in an environment, the role that ambient illumination plays in pedestrian fatalities was illustrated by Buonarosa, Sayer, & Flannagan (2008) who investigated the effect that relatively small illumination enhancements provided by the moon, have on pedestrian safety at night. On nights with a new moon (i.e. 0% illumination), the frequency of pedestrian fatalities increased by 22% relative to nights with a full moon (i.e. 100% illumination). This has subsequently been confirmed by Todd et al. (2015), who goes on to refine this association through his findings that only in the absence of artificial, urban lighting does the increasing phase of the moon have an impact on terrestrial illuminance.

While there can be little doubt that road lighting offers significant visibility improvements for drivers at night, the installation of street lighting can also have risk-compensation effects, where drivers use the increase in visibility to increase driving speed. The potentiality for road lighting to induce higher speeds was first reported by Assum et al., (1999). Assum, Bjørnskau, Fosser, & Sagberg (1999) investigated the association between roadway lighting and speed behaviour and theorised that drivers would not adjust their speed behaviour following the installation of street lighting. Their hypothesis yielded contrary results with the highest speed occurring during night time on roads with street lighting. Subsequent investigations were undertaken by Jägerbrand & Sjöbergh (2016) who reported similar trends. Analysing speed differences at night under different weather conditions on roads with and without street lighting, these authors found that in adverse weather conditions, greater decrements in speed were more common on roads without overhead lighting than on roads with overhead lighting. This indicates that the drivers did not adjust their speeding behaviour significantly on roads with street lighting even in poor visibility conditions.

2.5 Vehicle factors affecting night time driving

The level of illumination available to the driver at night substantially influences the disproportionality between exposure and the crash rate at night time. Illumination refers to the process of radiating energy in the form of light onto an object or surface to make it visible and clearer in darkness (Boyce, 2003). At night time, vision is severely degraded and visibility is limited. The driver's field of vision is restricted to the field of view illuminated by the vehicles headlights, roadway lighting, glare from opposing vehicles and ambient lighting from surrounding buildings and even the moon. Vehicle headlights play a crucial role in illuminating dimly lit roadways and providing forward lighting. Headlights illuminate the road ahead and provide light that extends beyond the drivers normal range of vision in darkness, makes the driver visible to oncoming traffic and other road users and illuminates road signs, other vehicles and pedestrians which aid in the detection of objects at night (Boyce, 2003).

2.5.1 High beams vs low beam headlights

Headlights play a significant role in providing forward illumination to detect vehicles, pedestrians and other targets at night. Motor vehicles are designed with two luminous intensity distributions, offered through high and low beams. While both beams play a vital role in seeing at night, they must work in tandem with each other to provide maximum forward visibility while minimising the unintended and adverse effect of glare on approaching drivers (Boyce, 2003). The illumination offered by low and high beam headlights is shown in Figure 2-5 and Figure 2-6.

Figure 2-5: Road surface illumination with high beam headlights

Source: Sullivan et al. (2004)

Figure 2-6: Road surface illumination with low beam headlights

Source: Sullivan et al. (2004)

High beams provide the maximum illumination at night. Light is distributed straight ahead onto the road surface and maximises sight distance (Boyce, 2003). This provides more forward visibility and enables drivers to see pedestrians at a greater distance. However, the higher the aim of the beams, the greater the amount of glare produced for oncoming vehicles. The lack of control in upward light produces glare which can have a temporary blinding effect on drivers in oncoming vehicles that look into the light (Boyce, 2003). Even though high beams increase the amount of light needed to see objects in darkness, they are unsafe to use when other vehicles are present on the road and are therefore mainly appropriate for use when driving alone on the road or in rural areas and open highways away from urban roads (Sullivan et al., 2004). In these cases, the likelihood of encountering oncoming traffic is reduced which means that the need to limit glare is also reduced. Figure 2-7 illustrates the amount of illumination provided by high beam headlights in right-driving countries which shows light scattered in the centre of the road surface and forward with greater amounts of light directed to the right side of the road (Buonarosa *et al.*, 2008). In left-driving countries like South Africa, the light will be scattered in the centre of the road surface and forward as well but a greater amount of light will be directed to the left side of the road.

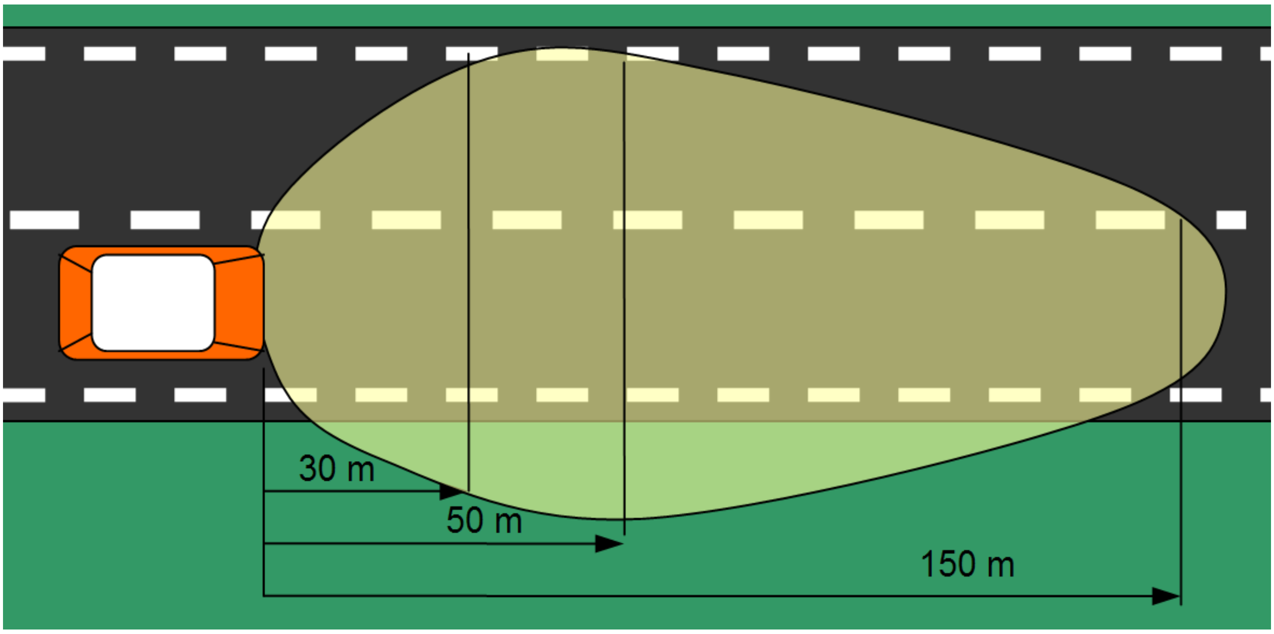


Figure 2-7: Symmetrical high beam illumination of roadway (right-driving traffic)

Source: Mefford et al. (2006)

Low beam headlights provide poorer visibility in comparison to high beam headlights. The beam pattern is lower so that light is distributed ahead and provides forward and lateral illumination in the roadway while minimising the effects of glare on approaching vehicles (Boyce, 2003; Shinar, 2017). Figure 2-8 illustrates that light output is directed downward and provides forward visibility more to the right side of the road. In South Africa, motorists drive on the left side of the road and light is scattered forward as well but a greater amount of light will be directed to the left side of the road.

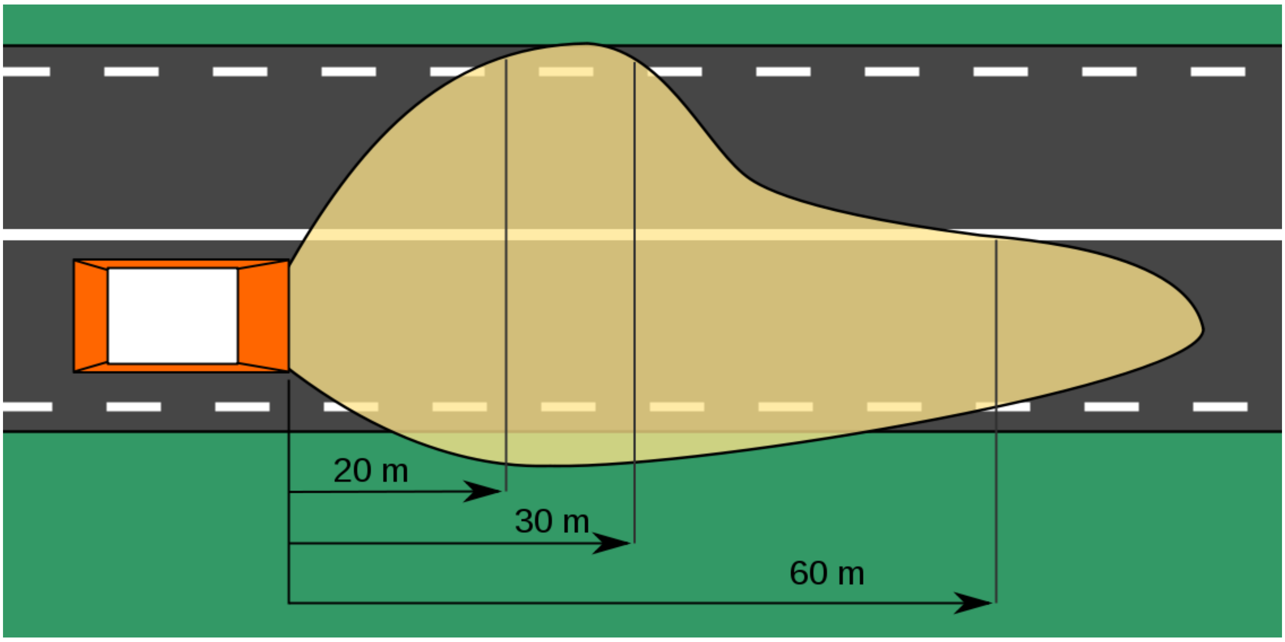


Figure 2-8: Asymmetrical low beam illumination of roadway (right-driving traffic)

Source: Mefford et al. (2006)

Depending on the side of the road that the vehicle is travelling on, the low beam headlights will provide greater levels of illumination to the right or left side of the road. In right-driving traffic the right side of the road receives a greater amount of light than the left side of the road (as depicted in Figure 2-8), because of the location and aim of the headlamps. In left driving countries, the inverse is true and more light is distributed to the left side of the road than the right side of the road (as Figure 2-9 illustrates), because of the location and aim of the headlamps.

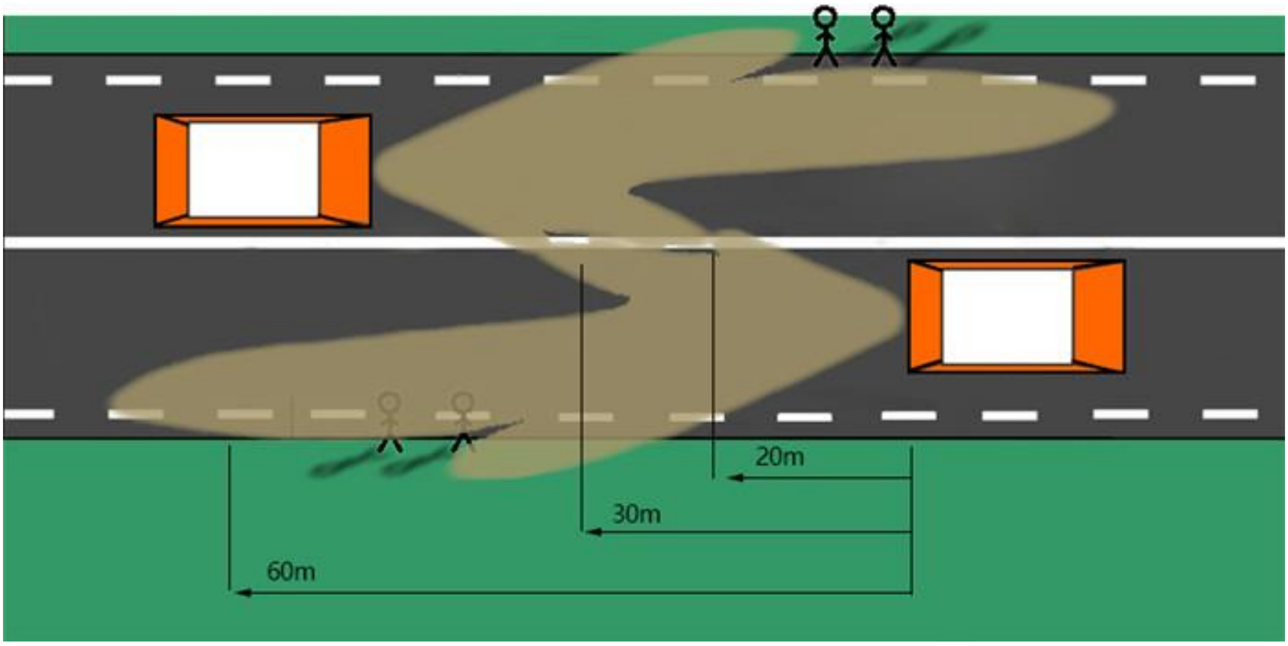


Figure 2-9: Low beam illumination for left-driving traffic

Source: Mefford et al. (2006)

This configuration of low beams affects object detection not merely because low beams inhibit maximum forward visibility but also because the design of the low beam distributes light more greatly onto certain segments of the road surface at the expense of other segments of the road surface (Buonarosa *et al.*, 2008). Low beam headlamps have been designed this way to minimise the light directed to the eyes of motorists in the opposing lane by dimming the headlamp (on the right side in South Africa). In left-driving countries like South Africa, more light reaches the targets on the left side of the road and as a result they will be seen from further away (see Figure 2-9). To inhibit glare to vehicles in the opposing lane, less light is directed to the opposite lane (right side of the road) which translates to reduced visibility for targets on the right side of the road. As a result, recognising objects when they appear on the dimmer side of the beams is more challenging and sometimes completely unsuccessful (Wood, Tyrrell & Carberry, 2005). The minimal light distributed to the right side of the road means that drivers will experience difficulty in seeing pedestrians that cross from the right to the left (Mortimer, Blomberg, Alexander & Vingilis, 2005). Pedestrians will appear more visible once they enter the lane that includes higher intensities of light, which is the left lane. When pedestrians cross from the right side of the road, drivers are unaware of pedestrians and receive less warning as pedestrians may be outside the visibility distance provided by the headlights, compared to when they cross the road from the left side (Buonarosa *et al.*, 2008).

2.5.2 Headlight beam use and driver safety at night

While low beams succeed in preventing or reducing glare to oncoming vehicles, the light intensity provided by low beams do not provide sufficient illumination to assure safety and maximise the visibility to allow drivers to identify and respond to hazards further ahead or in dimly lit road environments (Helmers & Rumar, 1975; Olson & Sivak, 1983). From a safety and visibility perspective, the illumination provided by high beams is superior, relative to low beams. High beam headlights are more powerful and are designed to enhance and extend the visibility distance available to drivers at night by projecting greater illumination onto the roadway, further ahead of the vehicle. In so doing, high beams offer substantial visibility benefits to detect vehicles, pedestrians and dimly-lit objects such as disabled vehicle and animals in the road.

Appropriate and consistent use of high beams have been shown to increase the visibility distance further ahead of the vehicle and enable the driver to identify and react to hazards quicker (Reagan, Brumbelow, Flannagan & Sullivan, 2017). High beam headlights provide significantly longer sight distances than low beam headlights. The earliest study demonstrating this relationship was conducted by Roper and Howard (1938), who reported that the illuminating power of higher beams is directly proportional to longer visibility distances. In addition, it was also noted that the low luminance of pedestrian clothing exacerbates drivers' ability to detect pedestrians under these illumination conditions which indicates that pedestrians contrast and beam illumination work in tandem to promote pedestrian conspicuity at night. This hypotheses is confirmed by Wood, Tyrrell and Carberry (2005) who measured visibility distances of pedestrians under varying reflectance conditions using a test track. The mean distance at which drivers responded to a pedestrian was increased by a factor of 2.6 for higher contrast objects (white-clad pedestrian) and by a factor of 3.5 for lower contrast objects (dark-clad pedestrian) when drivers used high beams as opposed when they used low beams. In this study, higher beams were particularly useful for low contrast pedestrians which broadly characterise the majority of pedestrians in traffic at night.

The superior visibility of high beams over low beams is not limited to larger and dynamic targets such as pedestrians; even smaller and static objects are more visible to drivers using high beams than low beams. In a field experiment performed by Reagan and Brumbelow

(2017) mean detection distances were uniformly longer when driving with high beams and drivers' also detected small (8x12 inches) grey roadside objects 28.4 m earlier with high beams than with low beams. At 32 km/h, a visibility distance of 28.4 m translates into an increase of 2.1 s for drivers to recognise and react to potential roadside objects which is a large safety benefit; given that brake reaction time for unexpected objects is 1.5 s (Green, 2000).

Olson & Sivak (1983) also found shorter visibility distances associated with low beam use when comparing the visibility distance to the stopping distance in response to darkly-clad pedestrians. The visibility distance was often shorter than the required stopping distance which means that even though drivers detected the pedestrian, they would not be able to stop in time to avoid the target. This was observed 45% of the time for young drivers (30 years old and younger) and 83% of the time for elderly drivers (65 years old and older). The results demonstrate the inadequacy of low beams to sufficiently illuminate low contrast pedestrians and provide enough time for the driver to avoid a crash.

Even when drivers are driving at legal speeds the visibility distance relative to the stopping distance under low beam lighting is still shorter. Johansson & Rumar (1968) investigated realistic visible distances and safe approaching speeds of motorists on non-illuminated roads. Safe driving speeds that would enable drivers to recognise and react to unexpected hazards on the road with low beam illumination, ranged from 25 to 50 km/h. In terms of safe stopping distances, Leibowitz, Owens, & Tyrrell (1998) reported that motorists driving at a speed of 40 km/h using low beams require a stopping distance that is 1-3 times greater than the visibility distance offered for a darkly-clad, unexpected pedestrian. Even when speed is reduced as low as 32 km/h, alert drivers may still fail to detect pedestrians in time to stop and require a total stopping distance of at least 29-38 metres.

The appropriate use of headlights can substantially diminish the visual impairment drivers experience at night and several studies have consistently showed the superiority of high beams over low beams in maximising roadway illumination at night. Reliance on low beams in situations that warrant the use of high beams contributes to increased crash risk for the driver, other vehicles and pedestrians as drivers experience difficulty in recognising targets under low illumination. Although a direct link between decreased visibility from vehicle headlights and the incidence of crashes has yet to be established, it suffices to say that shorter visibility distances obtained by low levels of illumination result in smaller reaction times on the part of the driver which advances the likelihood of a crash occurring.

2.5.3 Real world use of headlight beams

It is generally recognised that the visibility afforded by low beams is insufficient to support safe driving in many driving contexts and chiefly in the absence of overhead street lighting (Shinar, 2017) and at speeds that exceed 70 km/h (Perel, Olson, Sivak & Medlin, 1983). Given that these factors largely characterise most driving situations at night, the main thing a driver can do to improve visibility in any vehicle is to activate their high beams in situations that sanctions its use. Yet from as early as the 1960’s, studies have reported that drivers rarely use their high beam headlights at night. In the US, Hare & Hemion (1968) first examined the real world use of headlamp beam usage at 17 locations, of which the majority (14 of 17) were two-lane, unlighted rural highways where visibility is markedly poorer. Observations were made regarding the initial beam usage, beam change in response to opposing vehicles, distance from opposing vehicle when beam change was activated and in the presence of leading vehicles.

Overall, the findings reveal a gross underutilisation of high beam headlights across all locations, with regional usage ranging from only 10% (Northwest) to 40% (Southwest). In open road situations, characterised as dark rural roads with no opposing traffic and no lead vehicle within 183 m and in clear weather conditions, only 25% of drivers used high beams, and more than 75% used low beams (Hare & Hemion, 1968). In car-meeting situations, characterised as a situation where the driver is 305 m or less from the opposing vehicle, 93% of drivers used low beams and 7% used high beams. However, it was also reported that drivers dimmed their headlights at distances that were significantly longer than is advisable for obstacle detection and occurred at dimming distances when disability glare would not impair the vision of oncoming traffic. Drivers switched from high beams to low beams at an inter-car distance of 522 m, although Helmers & Rumar (1975) report that a distance of 250 m to 400 m is optimal.

The finding that over 75% of night time drivers used low beam in situations where high beam use was advisable, feasible, and prudent and would have drastically increased the visibility of the road environment without causing glare discomfort and disability to approaching drivers is staggering. Since that time it is anticipated that developments in vehicle lighting in terms of beam pattern design, the advent of dimming controls, modifications to the traffic environment and improvement in driver awareness regarding the hazards of limited visibility may have sufficiently altered driver behaviour in favour of high beam usage. However, this phenomenon is not unique to motorists in the sixties as subsequent findings over the years have emerged reporting similar trends on the infrequent use of high beams in situations that warrant and justify its use.

In 2004, Sullivan, Adachi, Mefford and Flannagan surveyed the use of high-beam headlights of 1740 vehicles, in the absence of other roadway traffic on three unlit local rural roadways using photometric measurements and observational data of oncoming vehicles. The selected sites were two-lane roads situated in rural areas that are free of fixed illumination, approximately level and straight along the 1500-2400 observation areas with traffic density ranging between 20 and 300 vehicles per hours. This is similar to the range used by Hare and Hemion (1968) and also consistent with actual night time traffic densities. The characterisation of a clear vehicle situation was slightly more conservative compared to Hare and Hemion and is defined as the situation in which a vehicle is unopposed by any oncoming traffic within sight distance, not following a leading vehicle and not being followed by another vehicle (Sullivan *et al.*, 2004). Under these conditions, observational data reveals that drivers use high beams only 50% of the time, which is slightly higher than the proportion of high beam use reported by Hare and Hemion. Roadside photometric measurements demonstrates that 42% of drivers drove at an illuminance criterion of 1.05 lux (this criterion was used to distinguish between high and low beams activation with measurements at or above 1.05 lux appraised as high beams and measurement below 1.05 lux appraised as low beams). Overall, these results indicate that little has changed since 1986 and the use of high beams in situations that warrant its use remain low.

Using a secondary analysis of data obtained from field operational tests of two crash warning systems, Mefford, Flannagan and Bogard (2006) reported a significantly lower rate of high beam usage among drivers ignorant of the fact that data on their high beam usage was recorded. On rural roads, with no opposing or leading vehicle, drivers used their high beams only 25.4% of the night time distance travelled. Collapsed across all driver and road variables, high beams were activated only 3.1% of the distance driven at night. In terms of road type, high beam usage was greater on local roads (8.9%) and lesser on limited access roads (0.2%). High beam use also varied with age, with older drivers (60-70 years old) (8.6 %) reporting higher rates of usage, compared to young drivers (20-30 years old) (2.8%) and middle-aged drivers (40-50 years old) (3.5%). This means that older drivers use their high beams three times as much than younger drivers and may explain, among a myriad of other reasons, why young drivers are over-represented in night time traffic crashes.

The effect of age on high beam use has subsequently been confirmed by Buonarosa, Sayer and Flannagan (2008) who quantified high beam usage by studying secondary naturalistic data on the average annual use of automotive lighting equipment. The findings suggest headlight differences according to driver age and gender and are presented in terms of the average annual hours of use and minutes used per 100 km driven in Table 2-4 and Table 2-5 below.

Table 2-4: Average annual use of headlights in hours stratified by driver age and gender

Headlight	Average Annual Use (hours)				
	Young	Middle-aged	Old	Male	Female
High beam	7.3	12.5	10.8	8.5	11.8
Low beam	159.3	71.3	47.0	112.8	79.0

Adapted from: Buonarosa et al. (2008)

Table 2-5: Headlight use in minutes/ 100 km stratified by driver age and gender

Headlight	Use (minutes/100 km)				
	Young	Middle-aged	Old	Male	Female
High beam	4.6	14.8	24.2	7.4	14.5
Low beam	100.0	84.2	105.3	97.7	97.3

Adapted from: Buonarosa et al. (2008)

The results indicate that average annual use of headlights (in terms of hours) decreases with driver age. In terms of beam usage, older drivers used their high beams more regularly than younger drivers and this effect is more manifest when distance travelled at night is factored in (in terms of minutes per 100 km). Older drivers' (24.2 min/100 km) use of high beam is five times greater than young drivers (4.6 min/100 km). The discrepancy in the higher usage rate observed among older drivers can be attributed to the propensity of older drivers to adopt slower speeds and drive shorter distances at night time compared to younger drivers (Buonarosa *et al.*, 2008). At the very least, the results from this study and Mefford et al. (2006) suggest that older drivers are more prone to adopting compensatory behaviours to improve their visual capabilities while driving at night time, which demonstrates a greater appreciation of visual losses and impairment at night among older drivers. In terms of gender, high beam usage is higher among females than males. Male drivers (7.4 min/100 km) used their high beams almost half as often as female drivers do (14.5 min/100 km), even though they accumulated 34 percent more hours of night time driving than their female counterparts.

Regrettably, the trend among drivers to underuse their high beams at night does not seem to have dissipated over the years and a study as recent as 2017 continues to document low usage rates in conditions in which it is favourable to use high beams (Reagan, Brumbelow, Flannagan & Sullivan, 2017). In fact, this study employed the same observational technique as Hare and Hemion (1968), and reported that only 18% of drivers used high beam headlamps, with greater use rates reported for vehicles at rural sites than urban sites and only

20% of drivers switching beam settings between these sites. The use rate is a significant deviation from the 24-50% use rates reported in previous studies.

In South Africa, faulty headlights, low-use of headlights and the blinding effect of headlight glare were implicated in 9% of fatal traffic crashes in 2016 (Road Traffic Management Corporation, 2017).

Figure 2-10 indicates that almost 3% of crashes were attributed to headlights not being switched on. The latest annual traffic Offence Survey indicates that vehicle defects associated with headlamps was the 5th highest offence (4.3%) of the total offences reported in 2016 (Road Traffic Management Corporation, 2016). Even though vehicle headlights represent a smaller percentage of traffic offences and human errors, the severity of this parameter as a contributor towards night time crashes cannot be ignored. Furthermore, while these statistics show that vehicle headlights play a role in traffic fatalities, it is difficult to deduce from these statistics whether this is owing to low beam overuse or high beam underuse at night. However, similar to the trends observed in previous studies, it is anticipated that drivers underuse their vehicle's high beams in conditions in which it is judicious to do so. These expectations are derived from the high crash rates at night, overconfidence in driving ability and skill observed among South African drivers and lack of awareness of visual degradations at night that warrant the use of high beams. It is significant therefore to investigate beam use at night among South African drivers as this may shed light on the role that vehicle factors play in contributing to night time traffic crashes.

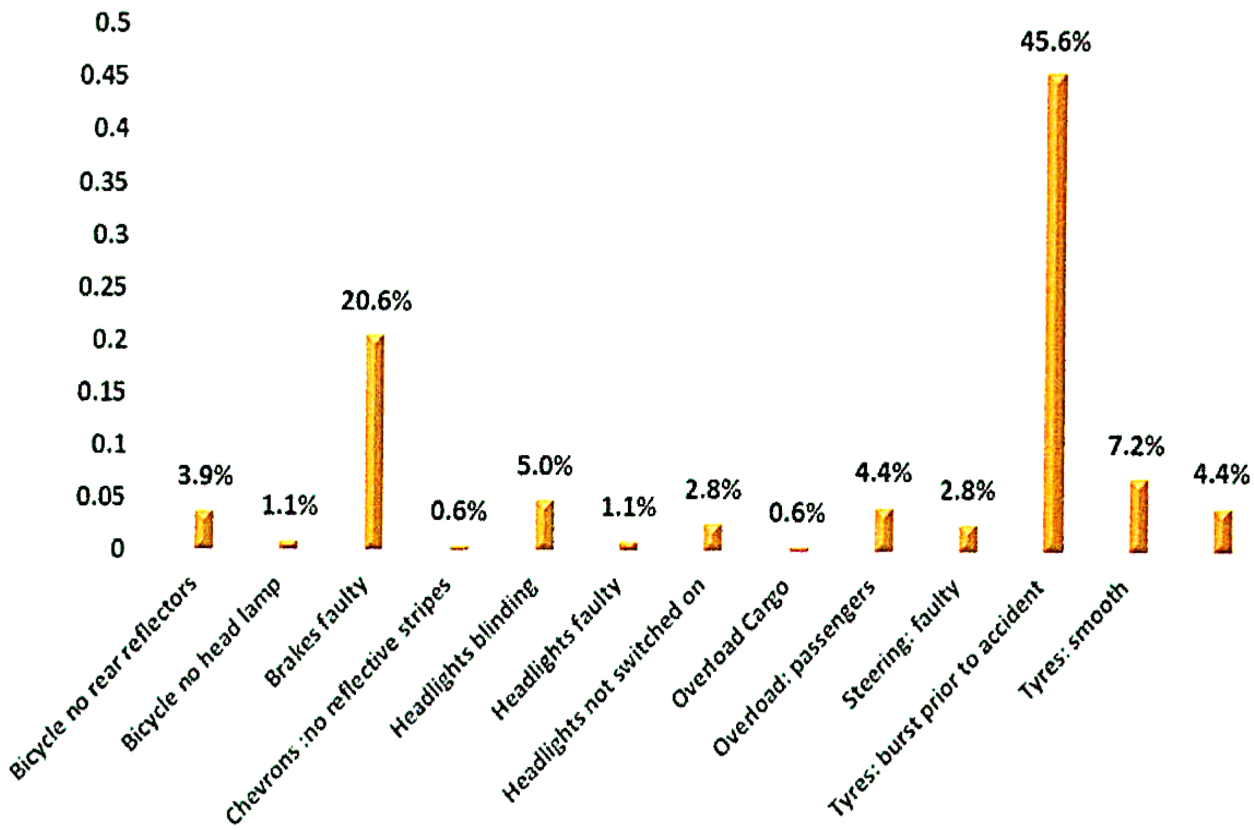


Figure 2-10: Percentage contribution of vehicle factors for traffic fatalities in 2016

(Source: Road Traffic Management Corporation, 2016)

The substantial reliance on low beams and underuse of high beams at night contributes to the increased risk of crashes at night with other vehicles and pedestrians as it is more difficult for drivers to see at night. Advanced headlight technologies such as high beam assist systems that use camera-based sensors to switch automatically between high and low beam headlamps based on the presence and of other traffic as well as ambient lighting hold considerable promise in addressing the substantial underuse of high beams at night (Reagan & Brumbelow, 2017). However, in developing countries such as South Africa where a relatively small subset of the population can afford to purchase vehicles with these advanced technologies, alternative methods that require less expense and effort should be used to increase high beam use among drivers. Understanding the reasons why drivers use their low beams significantly more often in driving situations, provides insight into the rationale driving their behaviour and aids in specifying target areas that need to be addressed to encourage the use of high beams.

2.5.4 Factors affecting beam use

The visibility produced by high beams maximizes the sight distance available to drivers by a considerable amount. Nevertheless, a series of studies have highlighted that the majority of drivers choose to use low beam as opposed to high beam headlamps in driving situations where it is safe and appropriate to use high beams.

A central factor contributing to the relative lack of high beam use is that drivers are ignorant of the marked visibility improvement achieved with the use of high beams (Hare & Hemion, 1968). If drivers are unaware of the enhanced visibility achieved through high beams compared to low beams then they are less likely to use this mechanism. Although this may be true for some drivers, the majority of drivers are in all probability, cognizant of the enhanced illumination obtainable with high beams. This is confirmed by Fekety et al. (2013) who reported that in a survey on driver, beliefs, attitudes and strategies regarding high beam use among young drivers, the majority of responses (88%) to the statement that they can see well with high beam headlights fell within the upper range (3-5) of the 5-item scale (ranging from very poor to very well).

A more plausible hypothesis is that drivers underuse their high beams because they are unaware of the extent to which they are visually impaired when driving with low beams. This lack of awareness can be attributed to drivers' overconfidence in their visual abilities at night and the misconception that low beam headlights provide sufficient compensation for visual losses incurred in the absence of ambient lighting (Leibowitz *et al.*, 1998). In addition to ignorance on the visibility benefits afforded by high beams, drivers may also be unacquainted with the operation of the vehicles dimming controls (Sullivan et al., 2004).

Some drivers may perceive the effect in roadway illumination between low and high beams to be marginal or be unperturbed by the limited visibility afforded by low beams, thus deeming the switching between and monitoring of the state of the headlamps, unprofitable. Certainly, it is reasonable to postulate that some drivers may even believe that they can see better with low beam because more light is directed onto the road immediately in front of the vehicle when low beam is used and they do not realise that this light does not extend far enough for adequate forward visibility and distance vision (Sullivan et al., 2004). The visibility benefit distributed by the vehicle headlights of leading and succeeding vehicles at inter-vehicle distances may also discourage high beam use (Mefford *et al.*, 2006).

Traffic density may also account for high beam underuse at night. Several studies (Hare & Hemion, 1968, Sullivan et al., 2004 and Mefford et al., 2006) have reported an inverse relationship between traffic density and high beam usage. High beam use declines as average traffic density increases which is consistent with common-sense expectation since the average distance between drivers also decline with increasing traffic density. As the frequency of potential roadway encounters increases, drivers appear less inclined to use high beams (Hare & Hemion, 1968). Notwithstanding that, Sullivan et al. (2004) discovered that even at the lowest traffic density, high beam activation never surpasses 70 percent, suggesting that additional factors beyond traffic proximity and the inexpediency of switching from low to high beams account for high beam underuse.

The infrequent use of high beams in situations that warrant and justify its use is also caused by driver inattention and refusal by the driver to be bothered with changing beams (Hare & Hemion, 1968). Drivers may consider it a nuisance to constantly switch between low and high beams and after a certain time they may stop doing it or forget to switch back to high beams after passing an oncoming vehicle and this inconvenience may explain driver's reluctance to use high beams. Advanced technologies such as high beam assist, which switches automatically between high and low beam headlamps could largely eliminate the underuse of high beams and the constant need for drivers to monitor the state of their headlights (Reagan & Brumbelow, 2017). Yet, a telephone survey on the attitudinal and motivational factors associated with high beam use revealed that only 43% of drivers indicated they opt for a vehicle with a system that automatically adjusted low and high beams (Reagan & Cicchino, 2016). Fekety et al. (2013) found that a larger proportion of drivers (64%) did not want adaptive driving beams, with drivers (73%) often citing concerns regarding the timeliness of the system to switch back and forth between beam settings, a bias of the system toward over-utilising high beams or a general mistrust of automation (Fekety *et al.*, 2013).

Not only do drivers forget to revert back to high beams, they may also be concerned about forgetting to dim the high beam at an appropriate time (such as in the presence of other vehicle) (Hare & Hemion, 1968). Many drivers may avoid the use of their high beams in order to prevent the occurrence of glare to other drivers, thus impairing their ability to see. Opposing vehicles may be concerned about aiming glaring beams into the eyes of oncoming drivers and succeeding drivers may be concerned about the effect of rear view-mirror glare on preceding vehicles (Sullivan et al., 2004).

Furthermore, road lighting may also influence the lack of high beam use. The overhead lighting at the test site in Hare and Hemion's (1968) study provided sufficient illumination to extend visibility distances that reach far beyond what automotive lighting can accomplish and it was observed that driver’s continued to use low beams in these circumstances as opposed to high beams. This suggests that drivers understand the superior power of overhead lighting in improving visibility compared to vehicle lighting (Hare & Hemion, 1968). However, this can be detrimental to safe driving as prolonged exposure and adaptation to environments where low beams are favourable, can result in drivers forgetting or neglecting to default back to high beams when entering roadways where its use is circumspect. Contrary results were observed by Reagan et al. (2017) who estimated the effect of urban lighting on headlight beam use rates. It was noted that sites with greater street lighting resulted in greater rates of high beam use than sites with no or low levels of overhead lighting. These results can be accounted for by absent-mindedness or the unwillingness and inexpediency experienced by drivers when reverting back and forth between beam settings as they enter and exit sites with varying overhead lighting.

There also appears to be a discrepancy between driver’s perceived use of high beams and their actual use of high beams. Reagan et al. (2017) reported an 18% high beam usage rate among drivers on unlit, rural roads in Ann Arbour in Michigan, USA. However, on another occasion when the driver population of Ann Arbour were surveyed on the use of high beams, 80% of respondents indicated that they always or almost always activate their high beams on unlit rural roads (Reagan & Cicchino, 2016). The time differences between these studies are too small to imply that the driver population observed and surveyed have significantly changed. In addition, estimation errors in perceived driving behaviour relative to actual driving behaviour are common among drivers as several studies have noted (de Craen et al., 2007 and Risto & Martens, 2014).

2.6 Biological factors affecting night time driving

Human performance is highly variable and subject to changes throughout the day. Our mental processes and behaviour are governed by our states of consciousness or awareness which has a major impact on health, safety as well as mental and motor performance. Daily changes in consciousness which are regulated by biological rhythms affect mood and motivation, thinking, decision-making, vigilance, situational attention, information processing and basic reaction time. At different times of the day we experience different rhythms in our physiology, behaviour and cognition and our energy levels ebb and flow with each hour of the day. Understanding the biology of human sleep and wakefulness and the inertial processes that govern our states of alertness or sleepiness can shed light on the internal biological mechanisms influencing driving performance and behaviour at night.

This section reviews the structure and mechanisms of the circadian rhythm and its associated biological processes that influence and govern human alertness and performance during day and night time. The rationale for including information on the circadian rhythm in human beings in the present work is that, interruptions to the normal and natural arrangement of the internal body cycle result in shifts to the phase of the body clock which translates into deficiencies in human performance at night. The operation of the body's natural rhythms and the effects of disruptions to this natural process are significant in uncovering and understanding how human driving performance is affected by these processes at night.

2.6.1 Biological cycles and circadian rhythms

Mental processes and behaviour are governed by our states of consciousness or awareness. Consciousness refers to the state of being aware of and responding to internal (emotion, huger, sleepiness, etc.) and external stimuli (seeing light or hearing sound, etc.). Human beings state of consciousness can fluctuate during the day, across seasons (daylight saving time) and throughout the human lifespan. Daily changes in consciousness are affected by biological rhythms and more specifically circadian rhythms (Dijk, Duffy & Czeisler, 1992).

Biological rhythms are internal cycles of biological activity that manifest in behavioural and bodily changes. A typical example of a biological rhythm is a woman's menstrual cycle- one complete, recurring, periodic menstrual cycle that takes about 28 days and produces a cyclical pattern of hormonal and physiological changes. Not all biological rhythms endure over a lunar month, some occur during the course of a day and this is referred to as a circadian rhythm. A circadian rhythm is a biological rhythm that occurs approximately over 24 hours and is therefore referred to as an internal biological clock. This internal clock regulates physiological processes that rise and fall every 24 hours such as heart rate, blood pressure, sugar levels, brain wave activity and core body temperature being exemplary of this process (Goel, Basner, Rao & Dinges, 2013).

2.6.2 Structure of the circadian rhythm

Biological rhythms denote that human beings possess an internal biological clock. The human body runs according to a natural biological clock of 24-26 hours which programs you to sleep at night and stay awake during the day (Goel *et al.*, 2013). Every human being's body runs according to a circadian clock, although there may be variation in when their biological clock tells them to sleep or wake up.

The circadian rhythm is aligned with the outside world and plays a major role in changes in the states of wakefulness and sleepiness in human beings. Figure 2-11 illustrates the operation of the circadian rhythm. The body's biological clock is situated inside the brain above the pituitary gland, in an area of the hypothalamus known as the suprachiasmatic nucleus (SCN) which responds to light and dark signals (Boyce, 2003). Sunlight is considered to be the most important '*zeitgebers*' (external time cues) in setting the circadian clock. This mechanism of the brain receives information on the amount of light present in the external environment from the axons of light-sensitive neurons in the retina of the eyes (Boyce, 2003). Depending on the time of day, the SCN signals the internal clock that is time to be awake or asleep (Brown, 1994). Other parts of the brain that regulate sleepiness and wakefulness such as hormones and body temperature also receive these signals.

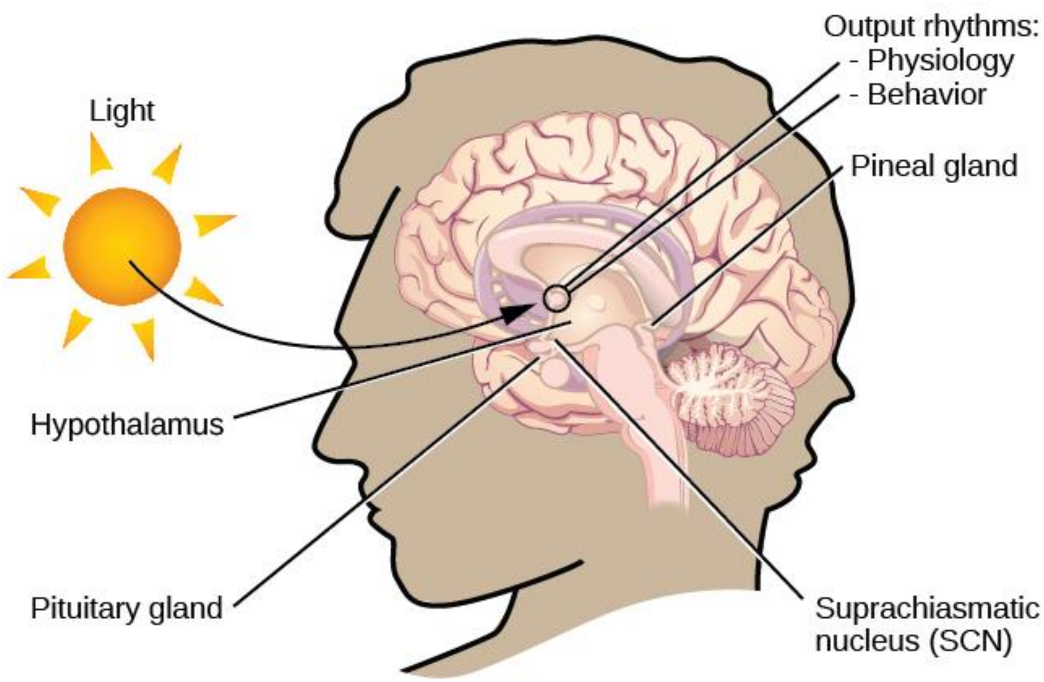


Figure 2-11: The circadian rhythm

Source: Goel, Basner, Rao & Dinges (2013)

The clock sets itself according to this information and is thus internally synchronised with the outside world. Changes in light intensity in external environments from daytime to night time secrete the hormone melatonin by the pineal gland, an endocrine structure located inside the brain (Brown, 1994). Melatonin is an important regulator of the circadian clock and uses light of suitable intensity as a primary time cue for synchronisation of the circadian rhythm (Arendt & Skene, 2005). It is associated with sleep onset and is stimulated by darkness (it peaks later at night) and is inhibited by light (it is lowest during the day and light exposure during dark hours also suppress melatonin production). It has acute sleep-inducing and temperature-lowering effects on the body which both reduce alertness in the individual and promotes sleep (Arendt & Skene, 2005). When morning dawns, and the exposure to light increases, the brain receives signals from the SCN to raise body temperature and secrete the hormone cortisol. The SCN also inhibits the release of melatonin (Brown, 1994). Other factors such as temperature, social interactions, exercise, drugs, alcohol and eating patterns can also affect the timing of the internal clock.

The circadian rhythm controls how alert an individual feels. According to Figure 2-12 below, the circadian alerting signal peaks around 6-8 PM and this would increase alertness in the individual. Conversely, between 4-6 AM the person would feel less alert. This rhythm repeats itself from one day to the next and is distinct from a sense of sleepiness that is related to how long a person has been awake (Van Dongen & Dinges, 2003).

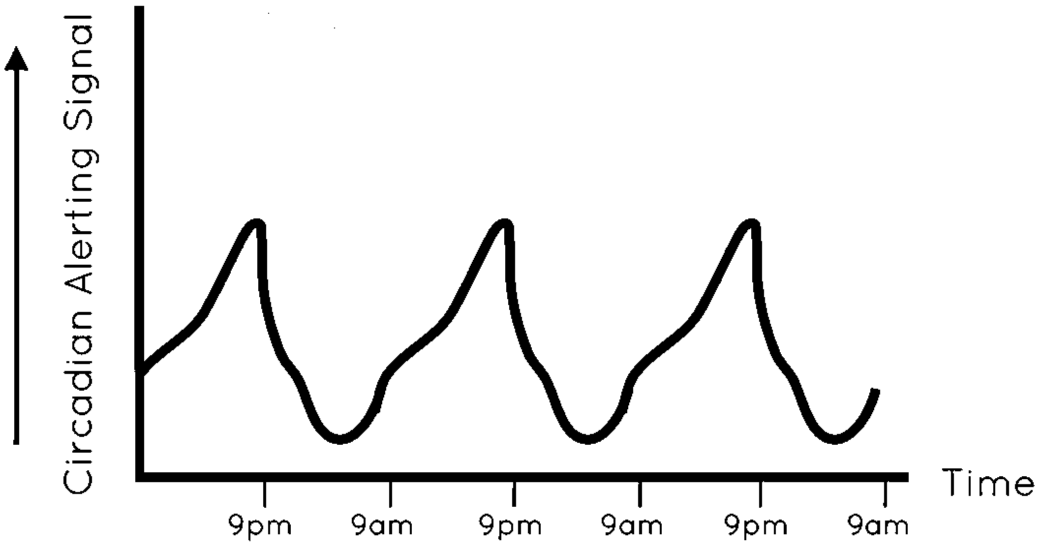


Figure 2-12: The circadian alerting system

Source: Van Dongen & Dinges (2003)

2.6.3 Sleep-wake cycles

Sleep is a significant part of every human beings daily routine and has numerous health, performance and safety implications. Cognitive performance and high levels of alertness during wakefulness depend on adequate, continuous and intense sleep in accordance with the circadian rhythm (Dijk et al., 1992; Goel et al., 2013; Wright et al., 2012). Circadian rhythms govern sleep patterns and have a profound impact on determining preferred time of sleep and wakefulness. The sleep-wake cycle of the human brain and body is linked to the environment's natural light-dark cycle and consequently plays a major role in our state of consciousness (Goel *et al.*, 2013). For most people, daytime is associated with being awake, attentive and engaged in activity. Night time, conversely, is associated with cooling down, rest, sleep and moving at a more relaxed and slower pace.

Regardless of our circadian patterns, the longer we are awake, the more fatigue exerts pressure on our bodies to rest. In addition to circadian drive (referred to as Process C), the homeostatic sleep drive (referred to as Process S) also regulates sleep and wake cycles. The homeostatic sleep drive is essentially an internal timer that urges and reminds the body to sleep after a certain amount of time that we are awake (Cajochen, Chellappa & Schmidt, 2014). With each waking hour that the body and brain are engaged in activity, there is a drive towards rest and recuperation of energy resources. Sleep pressure builds up as the waking day progresses and increases the desire and need to sleep (Van Dongen & Dinges, 2003) as illustrated in Figure 2-13 below. This pressure dissipates during sleep and rises again during wakefulness. The homeostatic sleep drive is a function of the amount of time elapsed since the last adequate sleep episode.

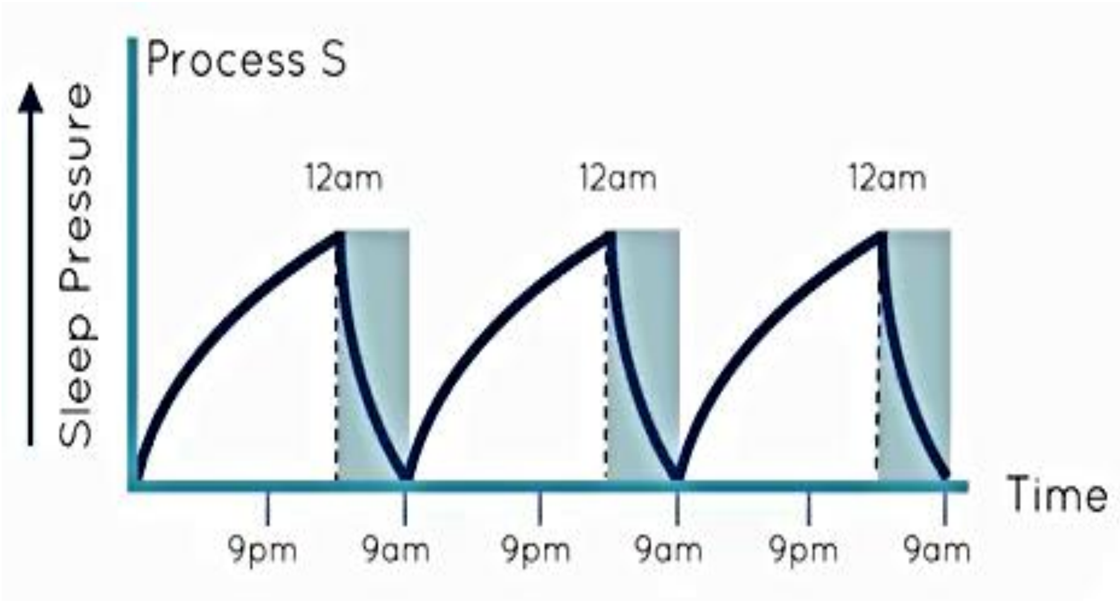


Figure 2-13: The homeostatic sleep drive

Source: Van Dongen & Dinges (2003)

While complete understanding on the mechanisms that underlie the sleep drive at the cellular level and measurement of its quantifiable aspects in the body has not yet been attained, scientists suspect that the neurotransmitter adenosine plays a central role. This hypothesis is derived from the relationship between adenosine and sleep drive which both accumulate in the brain tissue during waking hours and dissipates while sleeping (Huang, Urade & Hayaishi, 2011). Adenosine is thought to be a by-product of energy consumption by cells which produces a sleep-inducing substance in the brain that is accumulated with every waking hour (Huang *et al.*, 2011). Adenosine concentration levels peak during wakefulness, increases during prolonged hours of wakefulness, increases sleep propensity and decreases wakefulness by inhibiting the brain cells that are responsible for producing alertness (Porkka-Heiskanen, 1999).

The role the circadian clock plays in inhibiting sleep is critical. It prevents us from falling asleep whenever we feel pressure from the sleep drive to sleep at inappropriate times. In the absence of this timing mechanism, the sleep cycle would become haphazard and human beings would be prone to continuous and polyphasic sleep patterns as cats are. The homeostatic sleep drive is a process that causes a pressure to sleep and the circadian rhythm is a process that dictates the daily rhythm of sleep (Cajochen *et al.*, 2014). The circadian rhythm controls the oscillations between sleep and wake and tries to synchronise our sleep activities with the environment's light-dark cycle sleeping by reserving for night time and wakefulness for day time (Brown, 1994). This means that the circadian rhythm promotes alertness during daylight and promotes sleepiness at night. Sleep drive increases significantly during the day but is countered and moderated by the circadian drive for arousal (Van Dongen & Dinges, 2003). Sleep drive and circadian rhythm oppose each other during the day but eventually the circadian system yields to this pressure at night. At night, however, when melatonin is produced, the core body temperature is dropped and sleep is initiated, this opposition subsides and the sleep gate opens which is characterised as the period where the sleep drive is at its peak and increases above the circadian alerting system and the urge to sleep increases significantly (Van Dongen & Dinges, 2005). The dynamic interaction between these processes is depicted in Figure 2-14.

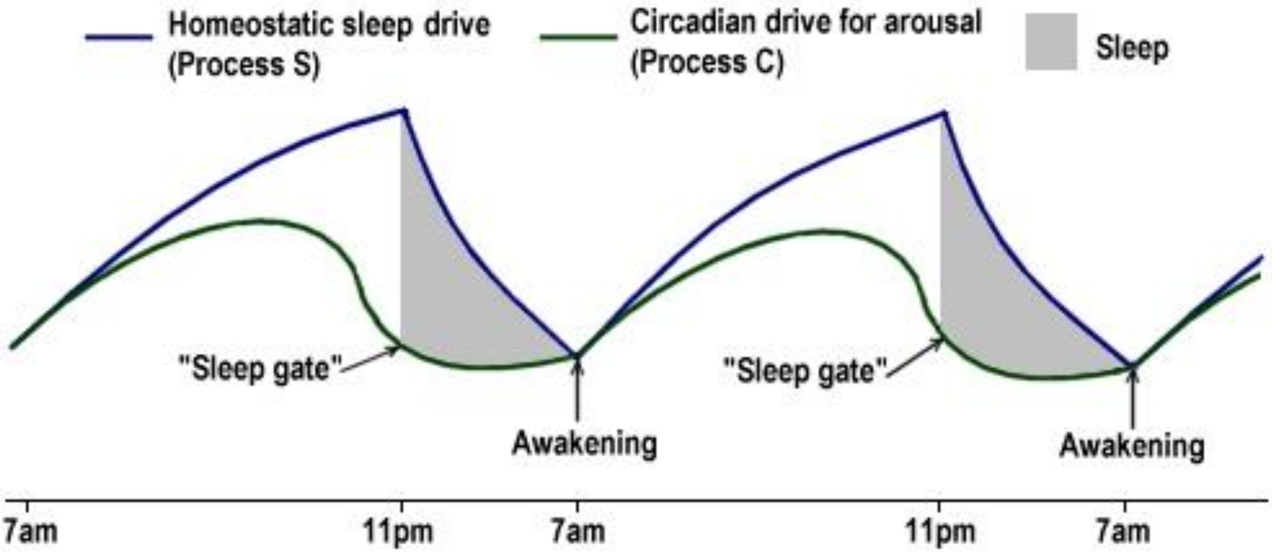


Figure 2-14: Interaction between the homeostatic drive (Process S) and the circadian drive (Process C) in the sleep-wake regulation

Source: Goel, Basner, Rao & Dinges (2013)

The wakefulness-promoting aspect of the circadian rhythm (promoting alertness during the daylight hours) and the sleep-inducing aspect of the homeostatic sleep drive (promoting sleepiness during daylight hours) work together to create a balanced sleep-wake cycle. However, these processes do not always work seamlessly together.

2.6.3.1 Diurnal vs nocturnal characteristics

Our internal body clock has programmed us to perform more excellently and efficiently at certain times of the day than others. Despite anthropological evidence demonstrating that earlier mammals were nocturnal, there is leading consensus in the scientific community that most humans are diurnal and have evolved diurnal characteristics (Ankel-Simons & Rasmussen, 2008). Diurnal organisms are mainly active during the day and sleep at night. Conversely, nocturnal organisms experience greater bouts of energy at night and sleep during the day.

While some people are temporarily or habitually nocturnal, human beings have evolved to be diurnal organisms and the ways in which the human brain, body and eyes have been designed and have evolved, buttress this. When it’s dark, the human body releases hormones that lower blood pressure, stress levels, body temperature and generally increases sleepiness. From an evolutionary standpoint, it is more advantageous for humans to be diurnal because their primary sense- the eyes- is suited to functioning better during daylight (Ankel-Simons & Rasmussen, 2008).

2.6.3.2 Morning preference vs evening preference

Despite individual preference for diurnal or nocturnal activity patterns (referred to as chronotypes), scientists generally concur that human beings have evolved to be diurnal. Chronotype refers to the behavioural expression of how the circadian rhythm embeds itself in an individual's body and reflects subsequent diurnal, nocturnal or cathemeral time-of-day preferences of mental and physical activity preference (Goel *et al.*, 2013). Researchers have traditionally used the terms morning-type (early birds) and evening-type (night owls) to describe these phenotypes. Chronotypes not only influence the circadian cycle but is also a manifestation of this biological pattern in the body (Goel *et al.*, 2013).

Family studies indicate that chronotypes are estimated to be about 50% heritable and several studies from molecular biology have consistently identified at least nine genes that contribute to determining individual circadian typology (Goel *et al.*, 2013; Kalmbach, Schneider, Cheung, Bertrand, Kariharan, Pack & Gehrman, 2017). At different times of the day we experience different rhythms in our physiology, behaviour and cognition and our energy levels ebb and flow with each hour of the day. Unlike a normal clock, these rhythms are slightly different for each person and vary not only in time but also pace (Dijk et al., 1992). Based on the biological clock or circadian rhythm, the body is programmed to function more productively and satisfactorily at certain times.

Depending on the circadian clock, people tend to be more active, perform specific tasks and sleep earlier or later in the day. For the majority of people, this may be either in the morning or at night, although some segments of the population are known to have intermediate or indifferent preference. Individuals with morning type preferences sleep earlier at night, are early risers, tend to feel more energetic just after they wake up in the morning and tend to function best during daytime hours while the individuals with evening type preferences are often awake at night, go to sleep later, feel most awake in the evening and are more productive during night time (Van Dongen & Dinges, 2000b).

Although, chronotypes are driven by genetic predispositions and relatively stable, circadian phase preferences do not remain uniform across the lifespan. It has been found that children and older adults are diurnal while adolescents are nocturnal (Buysse, Monk, Carrier & Begley, 2005). Adolescents experience a circadian shift due to a sleep phase delay brought on by lower levels of melatonin in the blood later at night compared to adults and children (Buysse, Monk, Carrier & Begley, 2005). Consequently, they feel alert later at night which makes it difficult for them to sleep earlier. This factor may shed some light on why adolescents and young adults are predisposed to driving at night compared to middle-aged and elderly drivers.

2.6.4 Effects of circadian misalignment on health, safety and human performance

Physiological limitations in vision at night have been recompensed with the emergence of technology and artificial lighting and this has enabled human beings to live nocturnally. Notwithstanding, the circadian rhythm is demonstrably geared toward being awake in daylight and sleeping in the dark. Thus it is more in tune with diurnal patterns of activity than nocturnal patterns of activity. In the course of a normal sleep-wake routine, the sleep pressure drive and circadian rhythm work in harmony. However, these processes can clash when you have to be engaged in work or perform activities at night since the circadian alerting system is at its lowest and sleep pressure is at its greatest. This non-linear interaction between the sleep drive and the circadian drive for arousal makes you particularly vulnerable to sleepiness related accidents and injuries and is more likely to affect individuals with nocturnal or evening-type preference than those with a morning-type preference. For individuals with diurnal tendencies sleep drive and circadian drive tend to be aligned- their energy levels are well synchronised with their body clocks and the transition of day and night. With the rising of the sun, external light tells their brain it’s time to wake up and increases alertness and when the sun sets their bodies have built up pressure to sleep and the circadian rhythm produces melatonin to prepare the individual to sleep (Brown, 1994).

Individuals who work at night on the other hand, have difficulty adjusting their biological clocks and must combat feelings of sleepiness brought on by sleep drive and melatonin production (Brugne, 1994). Because their activities take place at night, when the sun rises in the morning the light resets their circadian clocks and increases their wakefulness and alertness even though they experience pressure to sleep and low energy levels. When the sun sets at night, the reverse happens and the sleep pressure drive promotes wakefulness while the circadian clock promotes sleeping. Regardless of whether they get enough sleep beforehand, these individuals must combat their bodies' natural rest period and counteract the circadian rhythm to remain alert and high functioning at night. When individuals experience perturbations in the circadian system and sleep drive, their sleep, waking and health states are derailed leading to adverse effects on health, safety and performance (Burgess, Legasto, Fogg & Smith, 2012; Goel *et al.*, 2013).

Even slight changes in circadian rhythms of approximately one hour can affect human cognitive performance. Burgess et al. (2012) investigated the effect of circadian timing shifts brought on by daylight saving time and later sleep times on weekend on reaction time using the Psychomotor Vigilance Test. The optimal circadian phase angle was established as one hour before the start of melatonin production and the midpoint of sleep (this circadian phase angle is often reported in healthy individuals with an early midpoint characterising morning types while evening type have a later midpoint). Changes in performance resulting from convergence to or divergence from this optimal circadian phase were recorded and results indicate slower reaction time is associated with being further away from the optimal circadian phase both before bedtime and upon waking up. These findings are corroborated by Yang & Spielman (2001) who reported a decline in performance on memory and verbal fluency tasks as a result of sleep phase delays on weekends (two hour delay).

Chronotypes may also influence socioeconomic outcomes and success in the workplace. Society is more amenable and accommodating of diurnal sleep patterns than nocturnal ones, by virtue of the fact that most companies and industries have business operating hours and working hours that favour morning types above evening types. In addition, given that morning-types are more likely to work when their bodies and brains are efficient, energetic and productive and that working schedules are in sync with diurnal circadian timing, it is expected that economic performance between this group and evening types would differ, with morning type individuals reaping greater benefits from this arrangement than evening types. Seeking to establish whether the early bird does indeed get the worm, Bonke (2012) put this theory to the test by examining income differentials among Danish individuals with morning and evening type preferences categorised according to sleep rhythms. The findings indicate that income is a function of chronotypes (or at the very least sleep patterns), with morning types working more hours, sleeping more hours on weekdays and weekends and earning significantly higher salaries than evening types (4%-5% higher). This latter observation was especially striking for men.

Circadian timing plays a major role in human athletic performance and can mean the difference between winning and losing a race. Henst et al. (2015) investigated the effect of chronotypes on scheduled race time and marathon performance between South African and Dutch runners. The approximate start time of marathon races in South Africa is 06:30 and in the Netherlands it is 11:00. Using the HO-MEQ questionnaire to determine chronotypes, participants were classified on a spectrum ranging from morning to evening types. For both groups of runners, a positive correlation between early chronotypes and marathon performance was observed while a negative correlation between late chronotypes and marathon performance was observed (see Figure 2-15). The majority of the South African athletes were morning-orientated compared to the Dutch athletes, and also demonstrated better performance for early chronotypes than late chronotypes among the South African cohort. Within the South African cohort, runners who demonstrating a higher preference for mornings had considerably faster personal best race times compared to runners who demonstrated a preference for evenings. However, late chronotypes in the Dutch cohort demonstrated superior performance to early chronotypes in the South African cohort.

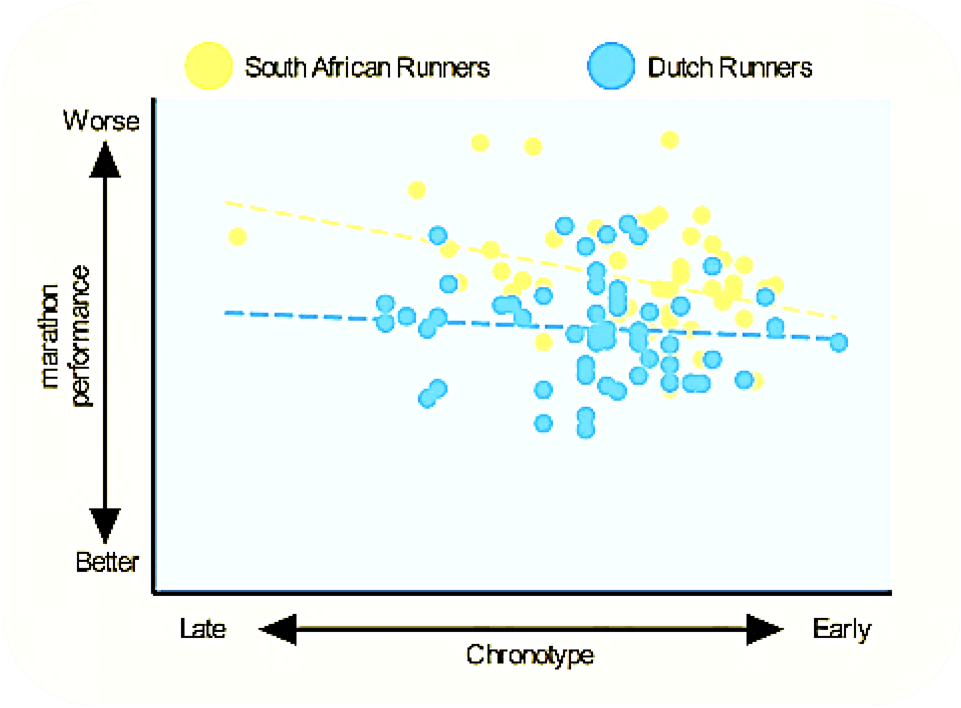


Figure 2-15: Marathon performance among South African and Dutch runners with early vs late chronotypes

Source: Henst et al. (2015)

Smith et al. (2013) reported similar athletic advantage in football players that were evening-orientated. Comparing performance among football players from Western and Eastern Time zones, the West Coast team defeated the East Coast team more often when playing football games in the evening. The results reveal that when playing football games in the evening, the West Coast team has a stronger athletic advantage over East Coast team. The West Coast team likely play closer to their circadian peak compared to players from East Coast. The authors conclude that the effect of circadian misalignment can profoundly compromise athletic prowess.

2.6.5 Fatigue-related vehicle crashes

Lack of sleep affects various cognitive structures such as attention, estimation, decision-making and perception-reaction (Dijk *et al.*, 1992; Goel *et al.*, 2013; Wright *et al.*, 2012) and generally leads to poor performance and a greater likelihood of committing errors and accidents. Given that the circadian rhythm has a profound impact on sleep propensity and alertness levels in the later period of the night, driving when the body should be resting increases the likelihood of being involved in a crash. Horne *et al.* (1995) found that driving between the hours of 04:00 and 06:00 AM resulted in a 10-fold increase in the chances of being involved in a crash compared to driving during the early evening or mid-morning period. Higher crash risks, particularly between the hours of 12:00 AM and 06:00 AM, have also been reported by Haworth and Rechnitzer (1993) and Folkard (1997).

Wilson, Fang, Cooper and Beirness (2006) studied the magnitude of sleepiness among night time drivers using self-assessment measures. A considerable amount of drivers reported feeling sleepy, with this amount increasing with advancing night time hours and in the early morning hours. Between 09:00 PM and 03:00 AM, almost one third of drivers reported some amount of sleepiness and 4% reported substantial sleepiness. Furthermore, the proportion of drivers feeling ‘sleepy’ increases to 45% and ‘very sleepy’ increases to 8% after 01:30 AM (Wilson *et al.*, 2006). Although the results obtained have not been validated by physiological measures, it nevertheless raises concerns about the safety of driving during the late hours of the night.

Although drivers are more vulnerable to fatigue at night, the period of night also influence the prevalence of crashes caused by sleep deprivation. Horne et al. (1995) reviewed 679 police reports on sleep-related vehicle crashes in the UK and identified incidence peaks at 02:00-02:59 Am, 06:00-06:59 Am and 16:00-16:59 Pm. The occurrence of crashes during the first time period is more profound given the low traffic density at this time of the night. Crash peaks in the early morning and late afternoon can be accounted for by the circadian propensity for sleep during these time periods which can result in drivers experiencing a drop in their level of alertness (Horne *et al.*, 1995). Sleep related crash peaks differ from peaks for all road crashes which are 07:00-08:30 AM and 17:00-06:30 PM. The greatest frequency of these crashes also occurred on weekends (Saturdays and Fridays) which indicates that the problem is further exacerbated by greater volumes of late night diving.

In terms of crash type, it has been reported on numerous occasions that rear-end crashes at night can be attributed to fatigue (Zhao *et al.*, 2014). Zhang et al. (2016) examined the impact of fatigue on car following behaviour. Time headways when following a leading vehicle and lane changes were recorded as participants navigated an on-road test and subjectively reported their level of sleepiness using the Karolinksa Sleepiness Scale (KSS) to an observer in the passenger seat. The results of the study indicate an indirect proportional association between level of fatigue and car following performance. When higher levels of fatigue were observed smaller time headways were maintained when drivers followed another vehicle and shorter time headways were selected when changing lanes (Zhang et al., 2016). When following a leading vehicle, trends indicate that when drivers felt extremely alert mean time headway of 2.37 s was maintained. During prolonged driving when alertness wanes and fatigue increases, mean time headway drops to 2.31 s and as feelings of fatigue progress mean time headway decreases to 2.27 s and 2.24 s, respectively. For lane changing behaviour, the average time headway decreased as fatigue increased; that is to say from 2.13 s (extremely alert) to 2.05 s (moderately alert) to 1.68 s (sleepy).

2.6.6 Drivers' awareness of fatigue

Fatigue plays a major role in crashes at night time and is often difficult to mitigate because drivers' may not be aware of the impact that fatigue has on their ability to drive safely. Research has shown that drivers are normally aware of when they are feeling sleepy (Horne, 1997). Thus, the decision to continue driving while impaired is a conscious one. Horne (1997) used a driving simulator on which participants whose sleep had been restricted to five hours the night before, drove for two hours in the afternoon on a monotonous road, to assess awareness of sleepiness while driving and awareness of the likelihood of falling asleep during the drive. The study showed that drivers were well aware when they were feeling sleepy, and generally were aware that this meant they might fall asleep yet they continued driving. From these results it is clear that drivers are aware when they are feeling sleepy, and so make a conscious decision about whether to continue driving or to stop for a rest. It may be that those who persist in driving are either unaware of the risk they are taking, underestimate the risk of actually falling asleep while driving or choose to ignore the risks (in the way that drink drivers do) (Horne, 1997).

Parnell (2014) has noted additional factors which make fatigue assessment difficult for drivers. These include the fact that drivers regard fatigue to be a more serious issue for long trips only, uncertainty about judging what level of tiredness impairs driving ability and decline in the ability to accurately assess tiredness as fatigue sets it. Furthermore, people often fall asleep more quickly than they realise or expect so drivers may underestimate the rate at which fatigue sets in Parnell (2014).

2.7 Visual factors affecting night driving

2.7.1 The human visual system

Most of the information used to drive safely is dependent on the visual system and as a result vision is the most significant sense required for driving. The significance of vision is recognised so prominently that the loss thereof or impairment to this sense warrants the loss or denial of a driver's license. It has been asserted that 90% of the information needed for driving is visual (Sternberg, 2004), although the source of this claim has been questioned by Sivak (1996) given that its estimation is not grounded in any scientific evidence. Nevertheless, this high estimation reflects the intuition of most researchers that vision exerts a powerful influence in driving and that it deserves serious consideration. The ability to perceive and react to stimuli and events in the environment is underpinned by the visual system which collects information using the eyes and transmits this information to the brain which interprets it and prepares an appropriate response (Townsend & Greenop, 2016).

2.7.1.1 Structure of the eye

Vision consists of sensation and perception. Sensation involves picking up sensory stimuli from the environment through the eye's receptor cells. This sensory input is then transmitted to the brain where the information is organised into a meaningful pattern and interpreted (Sternberg, 2004). The energy signal that the human eye receives is light. Light signals travel through the eye and is picked up in the form of wavelengths by specialist cells in the retina. Figure 2-16 illustrates the structure of the eye and the path that light travels through the eye.

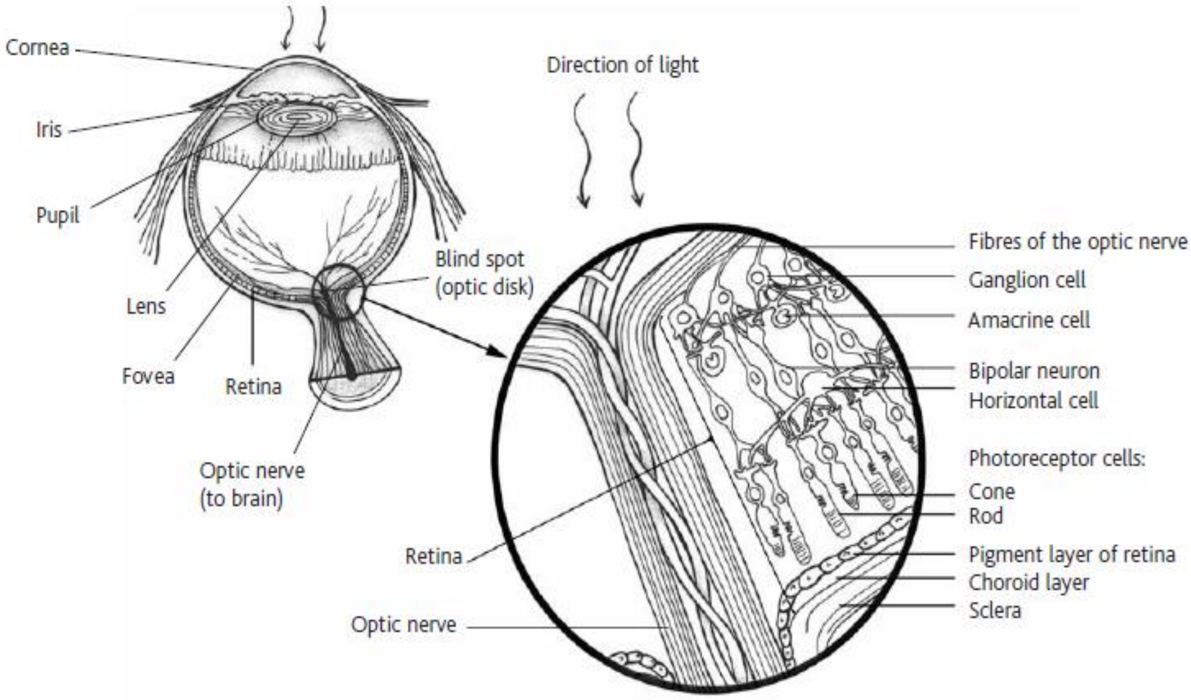


Figure 2-16: Structure of the eye and the path light travels to reach the photoreceptor cells

Source: Townsend & Greenop (2016)

There are two kinds of photo-receptor cells that respond to the various wavelengths of light: rods and cones. These photoreceptor cells receive photons of light and transduces them into neural signals for the brain (Townsend & Greenop, 2016). According to Bourne and Russo (1998), rods and cones are responsible for different aspects of vision.

- **Rods** are located on the periphery, are insensitive to colour and allow human beings to see in low vision and dark light. Rods function optimally under lower light levels.

- **Cones** are located mainly in the fovea (where best visual acuity occurs), are colour-sensitive and function best in bright light (Bourne and Russo, 1998).

2.7.2 Visual acuity at night

Visual acuity refers to the clarity and sharpness of vision in discriminating between objects and its details in the environment (Townsend & Greenop, 2016). Poor visual acuity diminishes the ability to see objects at a distance and perceive fine details of an object (Hills, 1980). The gravity and relevance of visual acuity for safe driving is derived from the fact that without good visual acuity, a driving permit is not attainable. Visual acuity is affected as the eyes progress through different stages of vision. There are three ranges of human vision, photopic, mesopic and scotopic, and these depend on the activation of the cones and rods according to ambient lighting (Reeves, 2009). Figure 2-17 shows the rod and cone operating ranges under different luminance levels.

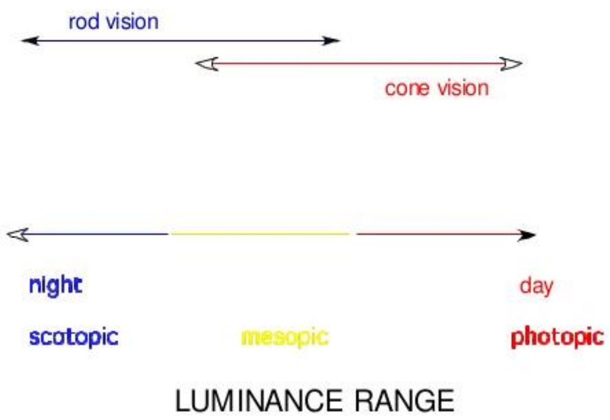


Figure 2-17: Rod and cone operating ranges

Source: Zele & Cao (2014)

The two sets of light-sensitive cells function differently during the three ranges of vision. In daytime, only cone cells are functional and eyes operate in the photopic range (Zele & Cao, 2014). Cones are most effective during daytime illumination and are responsible for sharp and detailed central vision (Reeves, 2009). Cones are dependent on light to work well and when the light is weak; they become ineffective and cannot register sharp vision. As ambient illumination decreases through twilight, the rods and cones operate together in the mesopic range (Zele & Cao, 2014). However, the effectiveness of the cones is diminishing which results in a reduction in the ability to discern colour and resolve fine detail of an object (Zele & Cao, 2014). At the same time, rods are not fully activated for night vision since they require more time to gain maximum retinal sensitivity (Zele & Cao, 2014). Both photoreceptor cells are compromised during the mesopic phase and perform inefficiently. In darkness, only rod cells are functional and this is referred to as the scotopic range (Zele & Cao, 2014). Rods are most effective during night time illumination and are responsible for peripheral vision (Reeves, 2009). When it is completely dark, rods have completely been completely activated for night vision but visual acuity and contrast sensitivity is severely reduced.

2.7.3 Selective visual degradation at night

Night driving is a situation for which humans have not evolved, and in which the human visual system proves inefficient (Rumar, 2001). Light is necessary for the human visual system to operate. Under low levels of illumination, the amount of light available is insufficient for the colour-sensitive cones and humans rely on their rods which are essentially inactive in high levels of illumination (Shinar, 2017). Given that human beings are not well adapted to seeing during twilight, it is expected then that drivers would adjust their driving behaviour by reducing their speed to compensate for visual limitations. However, several studies have shown that drivers rarely reduce their speed in changing lighting conditions and may even adopt higher speeds at night (Quaium, 2010, Valck et al., 2006, Bassani & Mutani, 2012, Senserrick et al., 2016, Jägerbrand & Sjöbergh, 2016). This begs the questions, why do drivers not change their speed if their vision is compromised at night? While the lack of risk compensation for visual losses may be owing to the fact that drivers are unaware of visual limitations experienced during night time, this ignorance can also be attributed to the deceptive nature of vision at night as characterised by the selective degradation hypothesis proposed by Leibowitz & Owens (1977).

Instead of a unified visual system, two separate modes of vision support guidance and recognition at night time (Owens, 2003). These neural mechanisms are focal vision and ambient vision. Focal vision supports visual recognition abilities and ambient vision supports visual guidance abilities (Owens, 2003). Both of these modes are crucial for driving and in particular, driving in dimly lit conditions. However, these visual modes can be functionally disassociated and are only selectively degraded in darkness (Leibowitz, Owens & Post, 1982).

Visual guidance abilities are concerned with vehicle guidance such as steering and lane-keeping while visual recognition abilities are concerned with recognising signs and hazards (Leibowitz *et al.*, 1982). At night time, visual guidance abilities remain highly efficient and functions as well as it does in daylight. Conversely, visual recognition abilities are severely impaired in darkness (Leibowitz *et al.*, 1982). Despite losses to visual acuity, recognition and colour perception, vehicle control skills such as steering and in particular, speed are relatively easy to maintain (Brooks, Frank, Isenhower, Klein, Addison & Tyrrell, 2004). The ability to maintain the vehicle and control speed effectively increases drivers' self-confidence and lowers risk perception. Since drivers are not aware of reductions in the ability to recognise hazards with the degraded focal mode and their confidence is derived from the ability to steer the vehicle with little difficulty, they have the impression that their visual abilities are still intact at night (Brooks *et al.*, 2004). In addition, since most of the objects in the road environment are designed to be retroreflective at night, drivers have very little opportunity to learn of their visual limitations at night (Brooks *et al.*, 2004). The preservation of visual guidance and the lack of awareness of the degradation of visual recognition abilities increases confidence in drivers' abilities at night and consequently, no adjustment to driving behaviour are made at night. This results in minimal or no difference in speed behaviour under degraded visibility conditions which means that drivers are unable to recognise and react to hazards timeously.

The selective degradation hypothesis explains why drivers make no adjustments to their deriving behaviour at night despite degradations to their visual abilities at night. It has subsequently been tested by Owens & Tyrrell (1999) and Brooks *et al.* (2004). Findings from both of these studies support the selective degradation hypothesis and show that visual acuity and not steering performance is degraded under extremely low luminance and extreme blur.

2.8 Speed behaviour at night

Driving conditions at night time are markedly different than day time. Among other risk factors, speed is one of the primary causes of traffic crashes. Drivers' select the speed at which they travel based on their perception of their own speed and their perception of the appropriate speed for the traffic conditions. More often than not, drivers select a speed that is too fast for conditions and adopt headway distances that afford insufficient preview time to react to the movements of vehicles, animals and other hazards in the road environment at night. Evaluating driver's' selection and judgement of safe and appropriate speed in conditions with high and low visibility provides insight into their speed behaviour and risk perception of driving at night time.

Speeding is at the core of the road traffic injury problem. While speed per se is not a problem, excessive speed (driving above the posted speed limit on a particular road) or inappropriate speed (driving at a speed that is not suitable for the road, weather, visibility and/or traffic conditions) is a major contributor to road traffic crashes worldwide. In high-income countries, excess and inappropriate speed is responsible for about a third of all deaths on roads (World Health Organisation, 2015). In low- and middle-income countries this number greater with speed accounting for a higher number of traffic deaths among vulnerable road users (Afukaar, 2003). In South Africa, the Department of Transport reported that excessive speed and inappropriate speed was implicated in approximately 30% of all traffic crashes and about 50% of commercial freight and public passenger vehicles (Sukhai, 2003). The number of fatalities attributed to speeding, increased by 1,093 (46,10%) from 2,370 in 2003 to 3,463 in 2004 (Bester & Geldenhuys, 2007). However, more recent studies indicate that the number of speed-related crashes appeared to be decreasing with approximately 18% of traffic fatalities in 2016 attributed to speed-related factors (Road Traffic Management Corporation, 2017).

In 2015, speed was recorded among the top five traffic offences in the 2015 Traffic Offence Survey, (10.8% of speeding offences were observed with manual hand held cameras and 24% of speeding offences were observed with fixed speed cameras) (Road Traffic Management Corporation, 2016). In a study on aggressive and hazardous driving behaviour among 1006 motorists in Durban, South Africa, Sukhai (2003) surveyed the incidence of high-risk driving behaviours. The results, shown in Figure 2-18 and Figure 2-19, indicate that more than 50%

of motorists exceed the speed limit half the time of driving and motorists also engage in this behaviour more frequently (mean frequency = 4.8) when an opportunity arose to do so. Other behaviours indicative of speeding propensity such as speeding up to an amber light (instead of slowing down or preparing to stop) and intentionally running red lights were also high. In particular, 48% of drivers engage in this behaviour and were 3.5 times more likely to engage in this behaviour when the opportunity arose to do so.

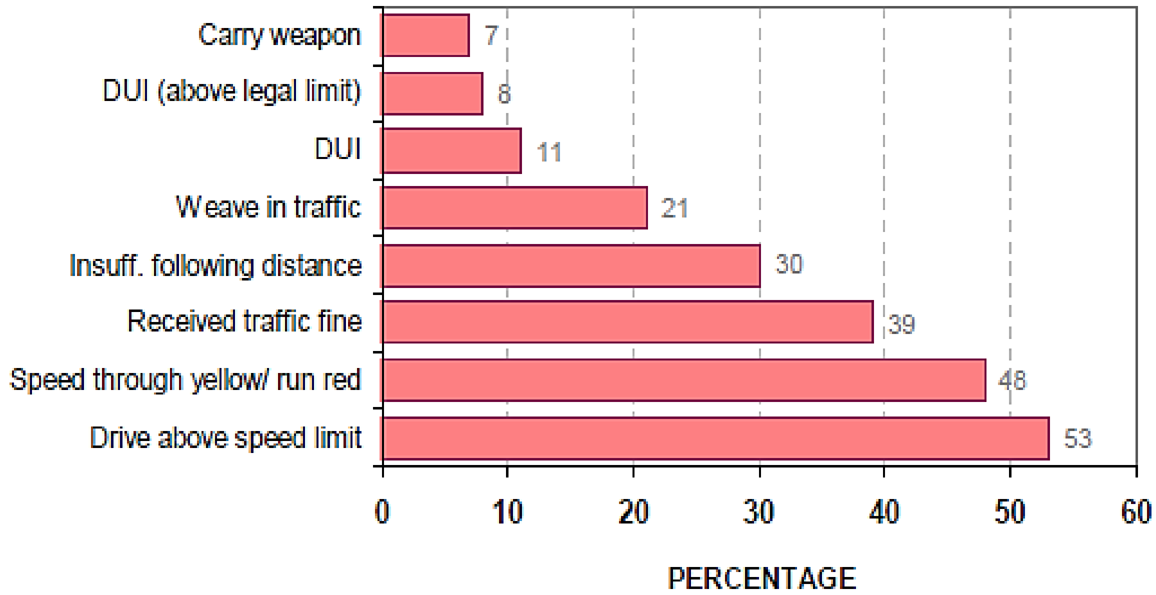


Figure 2-18: Prevalence of engaging in high risk-driving behaviour among motorists in Durban, South Africa

(Source: Sukhai, 2003)

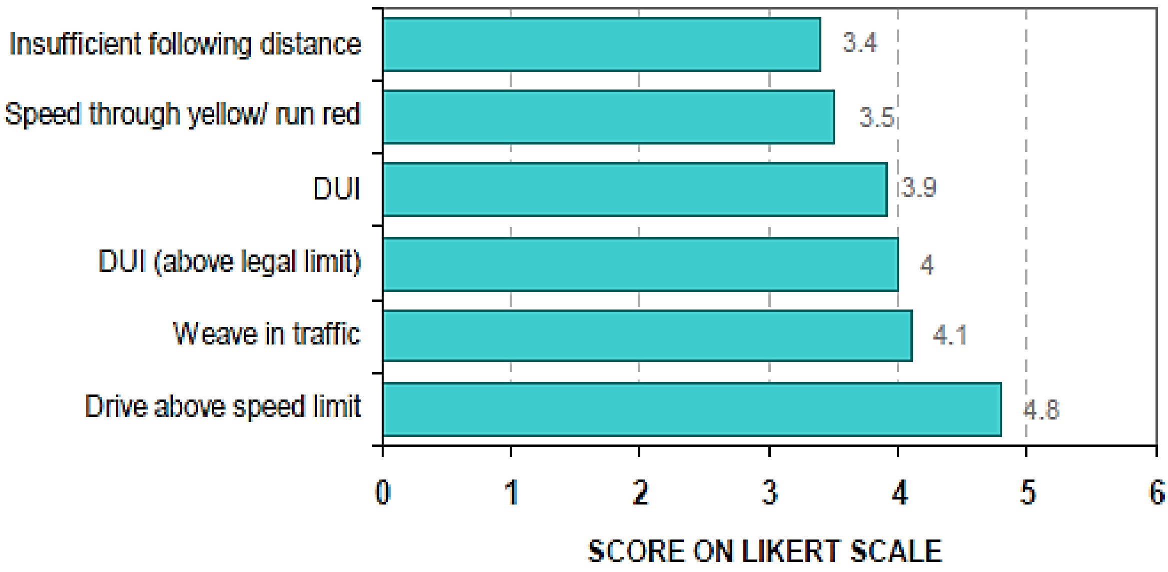


Figure 2-19: Frequency of engaging in high risk-driving behaviour on a scale of 1-10 among motorists in Durban, South Africa

(Source: Sukhai, 2003)

2.8.1 Crash risk and severity

Research shows that speed is one of the most frequently contributing factors to vehicle crashes. While there are additional factors that affect the relationship between speed and road traffic crashes such as road infrastructure, vehicle type and environmental conditions (Aarts & van Schagen, 2006), it is an established fact that the higher the speed of a travelling vehicle the greater the likelihood of being involved in a car crash and the greater the chance of sustaining life-threatening and permanent injuries in the event of a crash (Afukaar, 2003). According to the Global Status Report on Road Safety (GSRRS) (World Health Organisation, 2015), a reduction as little as 5% in average speed; can result in a 30% reduction in the number of fatalities while an increase of 1 km/h in average speeds results in a 4-5% increase in fatalities. Furthermore, for vulnerable road users such as pedestrians the chance of surviving a crash if struck by a car travelling at 50 km/h or less is 20% but the risk of dying if struck at a speed of 80 km/h is 60% (World Health Organisation, 2015). Even more vulnerable are child pedestrians, and the survival probability and likelihood of sustaining more severe injuries for these pedestrians are worse than that of an adult pedestrian. For example, for child pedestrians the probability of surviving a crash if struck at 48km/h is approximately 50% but at 64km/h the probability of surviving decreases to approximately 10% (Afukaar, 2003).

In the event of a crash taking place, the risk of being killed and sustaining severe injuries is higher at higher speeds. Scientifically, this is attributed to the laws of physics. During a crash, the kinetic energy of a vehicle is directly proportional to the weight of the vehicle and to the square of its speed (Aarts & van Schagen, 2006; Afukaar, 2003). This means that higher speed levels result in more dissipation of kinetic energy which translates into an increased likelihood being of involved in a fatal crash, greater injury severity to vehicle occupants and other road users such as pedestrians and greater damage to the vehicle (Aarts & van Schagen, 2006).

In addition, Göran Nilsson's (2004) power model on the relationship between speed and road safety proposed that there is a causal, law-like relationship between speed and traffic crashes. According to Figure 2-20, a 5% increase in average speed leads to a 20% increase in fatal crashes. The same graph also shows the crash-reducing effects of lower vehicle speeds. A 5% decrease in average speeds leads to an almost 20% decrease in fatalities. Overall, Nilsson’s power model illustrates that higher speeds result in a higher probability of being involved in a traffic fatality and incurring more severe injuries. These findings have been corroborated by Christensen and Amundsen (2005) through a meta-analysis on the statistical association between high speeds and crash frequency and severity. From their results, it is estimated that a 10% reduction in the average traffic speed will result in a 37.8% reduction in the number of fatalities (Christensen & Amundsen, 2005). These results give clear support to Nilsson’s model.

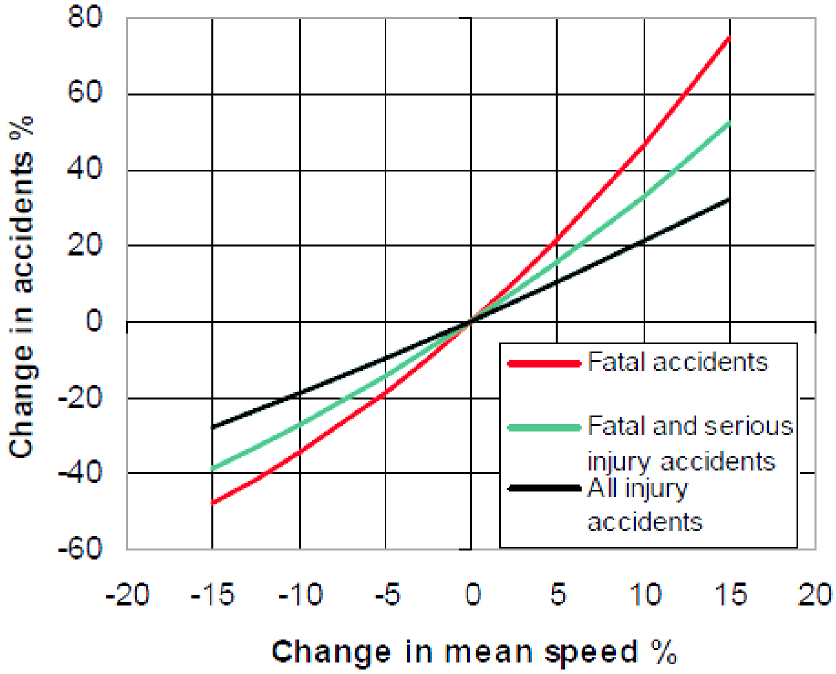


Figure 2-20: Nilsson's power model on the relationship between vehicle speeds and traffic fatalities and injuries

(Source: Nilsson, 2004)

2.8.2 Aetiology of speed and crashes

The underlying cause of speed-related crashes is attributed to driver behaviour and capabilities. Speed reduces the time/distance available for motorists and other road users to detect and react to unexpected and unfolding hazardous situations in the roadway. In addition, speed also alters the visual-perceptual capabilities of a driver. This is discussed in greater detail in the next sections.

2.8.2.1 Perception-reaction

The reaction time of drivers and braking time of the vehicle also contributes to the relationship between the frequency and severity of road traffic crashes and speed. Perception reaction time refers to the interval between obstacle appearance and driver response initiation (Green, 2017). At high speeds, the time available to process information, make decision and evasive manoeuvres accordingly is reduced (Forbes, 2012). This means that the distance covered during normal reaction time periods increases with an increase in speed. The distance travelled during the perception-reaction time of the motorist at a higher speed is increased which results in less space for manoeuvring to avoid a crash. Figure 2-21 displays the vehicle stopping distances at different speeds.

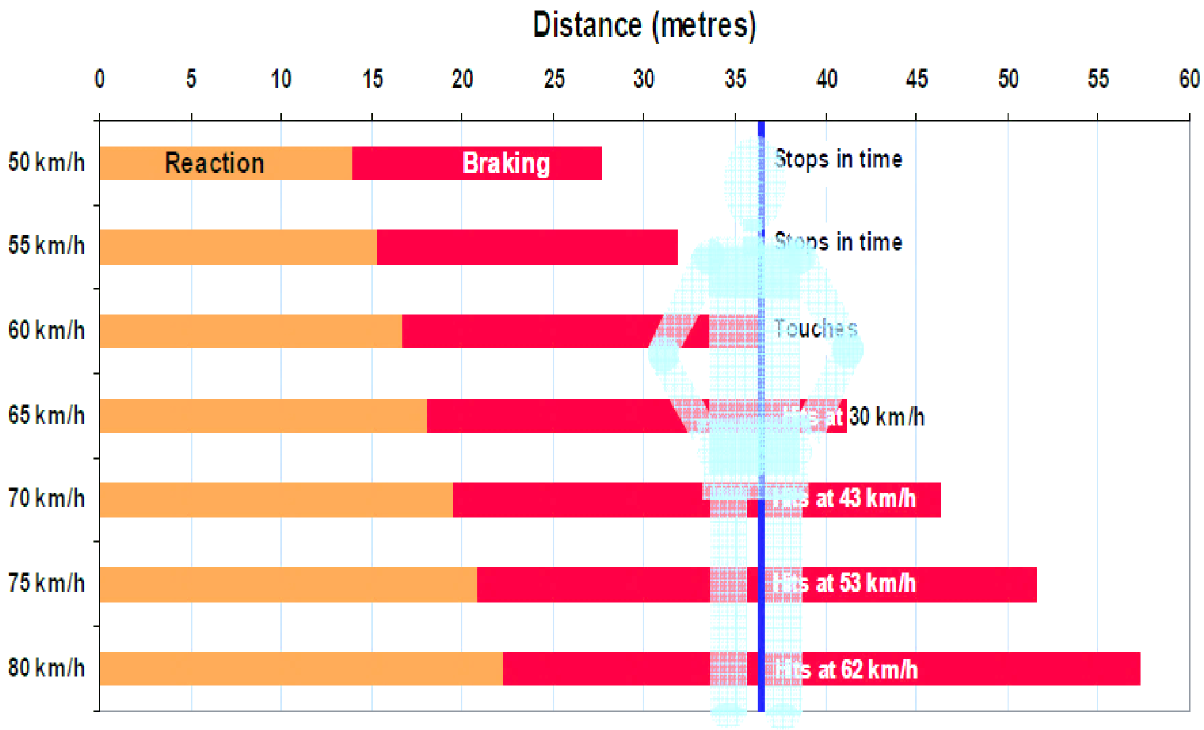


Figure 2-21: Vehicle stopping distances at different speeds (with a reaction time of 1 s) (Source: OECD, 2006)

According to Figure 2-21, a motorist driving at 80 km/h on a dry road will take about 22 metres to react to pedestrian and a total of 57 metres to come a stop. If a pedestrian enters the roadway at 36 metres ahead, the pedestrian will probably be killed at 70 km/h or higher but only injured at 60 km/h. While the possibility of avoiding the pedestrian is more likely at speeds of 50 km/h or lower, if the pedestrian enters the roadway 15 metres ahead of the drivers the probability of striking and injuring the pedestrian increases. The main impact of speed on perception-reaction is that speed reduces the amount of time available to respond developing hazardous situations in the roadway (Green, 2000).

Visibility plays a key role in perception-reaction time. While the same factors affecting reaction in daylight conditions operate at night, poorer visibility under conditions of darkness delay the detection time of an object and consequently increases reaction time. Under low illumination, the distance at which drivers can detect an un-illuminated and un-reflectorized hazard depends on the lighting power afforded by vehicle headlights, the drivers colour perception ability, and the expectation of encountering the hazard (Forbes, 2012). When driving at a high speed in poorly lit road environments, low-contrast hazards may not be detected timeously to initiate an evasive manoeuvres. Drivers' ability to respond to hazards under low illumination is further aggravated by a high mental workload at night time (e.g., traffic merging, reading signs), fatigue and visual impairment. At night time, a motorist's vision and the visibility provided by the road environment is severely reduced. An important source of illumination such as the vehicle's headlights cannot follow the curves, hills and dips in the road to provide sufficient visibility (Forbes, 2012). The combination of low contrast objects that often appear in the peripheral view of the drivers slows driver detection and response time. In addition, human vision operates in the mesopic range at night in urban areas, which means there is mixed rod-cone activation and as the rods become the primary photoreceptor, there is a sharp increase in the reaction time (Green, 2017).

Under conditions of darkness, drivers often fail to detect pedestrians, vehicles and other obstacles in the road, such as disabled vehicles and animals and are therefore unable to stop in time to avoid a collision (Rumar, 1990). Leibowitz et al. (1998) attributes this to drivers routinely over-driving the vehicles headlights at night. Overdriving the vehicles headlights occurs when drivers adopt speeds that are so high that the stopping distance is farther than the visibility distance provided by the vehicles headlights (Green, 2000). Drivers select speeds that do not compensate for the limited visibility distance afforded by headlights at night and therefore do not give themselves sufficient time to bring the vehicle to a complete stop or take alternative evasive actions once they have detected an obstacle in the roadway. In other words, the speed is too high compared to the visibility distance. Consequently, drivers often recognise and react to pedestrians at shorter distances and do not have enough time to avoid a collision. For example, although 50 metres is required in order to detect a pedestrian, apply brakes and come to a complete stop while driving with low beams, drivers usually detect pedestrians at an average distance of 35m (Shinar, 2017). Furthermore, reflective road signs and other roadside equipment mislead driver into thinking that they can see farther than they really can (Green, 2017), which means that they don't recompense for the limited visibility by driving at lower speeds.

Higher speeds reduce the amount of time to take evasive action should drivers detect an object. To drive safely at night, drivers have to reduce their speed and drive within the range of vision provided by the headlights. This provides them with more time to decipher and decide accordingly how they will respond to targets they encounter in the roadway at night. In addition, low contrast objects and pedestrians also exacerbate the crash potential. Visibility of pedestrians at night is so poor that maximum speeds at night would have to be substantially reduced from 25 to 70 km/h to ensure drivers have sufficient time to avoid striking a darkly-clad pedestrians (Johannson & Rumar, 1968; Leibowitz et al., 1198).

2.8.2.2 Field of vision

Vehicle speed affects the complexity of the visual scene at night time. As vehicle speed increases, the visual field is reduced and the rate of change of the visual scene increases as well. Consequently, the amount of visual information that is available to process increases substantially. Because drivers are not able to process the large amounts of information they receive, the brain responds to the information overload by subconsciously narrowing the search scope and eliminating some of the input (Forbes, 2012).

Figure 2-22 shows the relationship between speed and its effect on the visual field. A driver's normal visual field is approximately 180º when stationary. However, as speed increases the drivers' visual field begins to constrict and becomes more concentrated on a single point in the forward view. At 40 km/h, the drivers' visual field reduces significantly and is halved to 100°. At this speed, the visual field is expansive enough for drivers to detect hazards and obstacles in the peripheral view. At 100 km/h, the horizontal visual field is severely narrowed and covers less than 40°, which considerably reduces the capability of the driver to assess potential danger. Fundamentally, higher speeds undermine the capability of the driver to assess, analyse and take action to avoid hazardous events unfolding in the periphery.

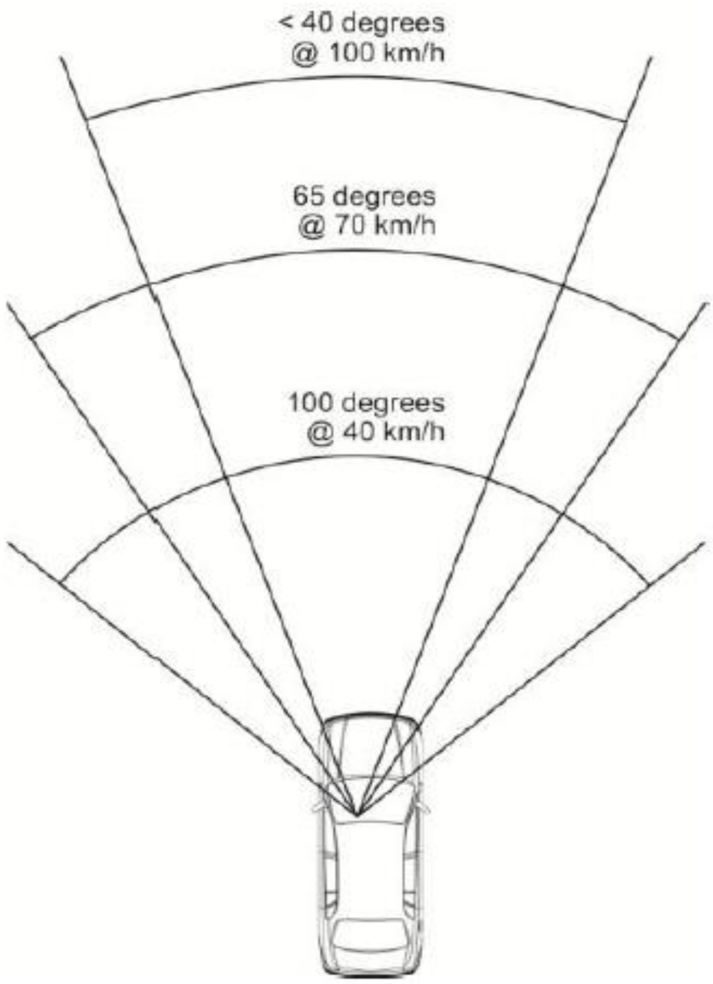


Figure 2-22: Effect of speed on driver's field of vision

Source: Forbes (2012)

The effect of speed on vision is not only limited to restrictions to the drivers peripheral view. Speed also affects the drivers' focal point in the forward view. Figure 2-23 shows the influence of operating speed on drivers' focal point.

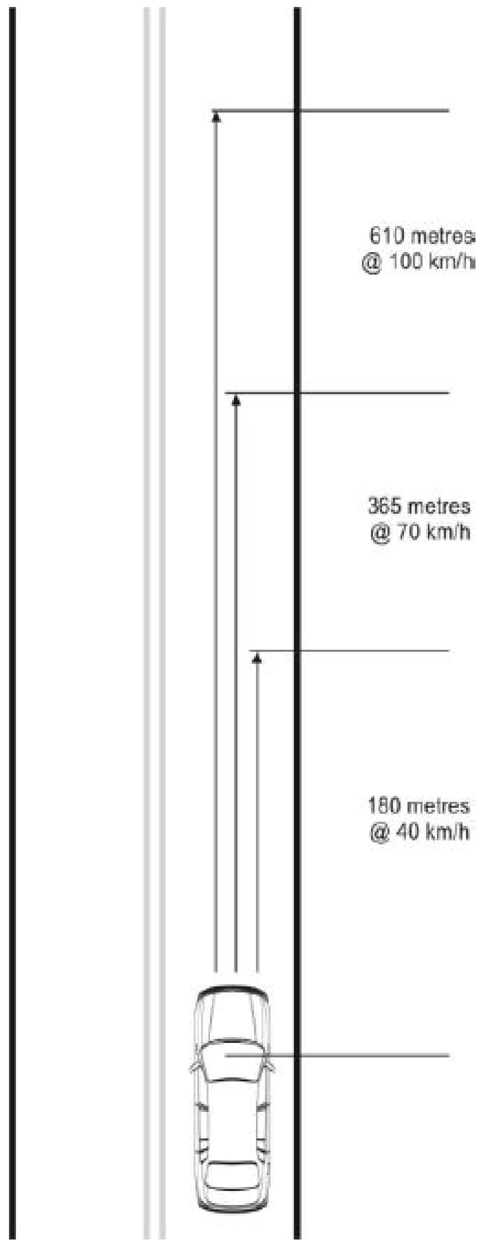


Figure 2-23: Driver Focal Point Related to Operating Speed

Source: Forbes (2012)

As speed increases, drivers need to process information from further down the road to make timely decisions on the speed and future path of the vehicle. This causes drivers to shift their point of focus further ahead and it becomes more challenging to notice events and conditions that are happening directly in front of the vehicle. At higher speed drivers can still afford visual attention to objects outside of the restricted field-of-view. However, shifting the gaze and attention to search for objects in the periphery increases the probability of these objects going undetected (Forbes, 2012).

2.8.3 Speed choice at night

Despite reduced visibility, several studies have shown that drivers rarely reduce their speed in changing lighting conditions and may even adopt higher speeds at night. Quaium (2010) investigated day and night time operating speeds at rural horizontal curves and found no statistical difference between speeds under different lighting conditions. In their study on the effect of weather, light and road lighting conditions on vehicle speed, Jägerbrand & Sjöbergh (2016) reported negligible speed differences between daylight and darkness. These results indicate that drivers do not adjust their speed behaviour at night. Drivers may even adopt higher speeds at night. Bassani & Mutani (2012) examined driver speed under day and night time lighting conditions and reported higher speeds at night time relative to daytime, in particular on roads with posted speed limits higher than 60 km/h.The increase in speed at night time was attributed to the increased presence of young male drivers on the road at night (who are known to adopt higher speeds) and the decreased presence of older drivers and women (who are known to be slower drivers) (Assum *et al.*, 1999). One study found lower average speed under low illumination, but reported that these decrements in speed was not enough to compensate visual recognition losses at night time (Owens et al. 2007). These results suggest that drivers misjudge their visual performance at night time.

2.8.3.1 Factors affecting speed choice at night

1. **Driver-related factors**

    a) **Driver age and gender**

Age and gender are commonly recurring themes in terms of individual differences in speed choice between drivers. In their analysis of driving safety behaviour in the US, Shinar, Schechtman and Compton (2001) reported that the percentage of drivers observing the speed limits all the time was higher for females (45%) than for males (36%). In terms of age, fewer young drivers (28% for drivers aged 25 and younger) reported observing speed limits all the time compared to middle-age (42% for drivers aged 26-50) and older drivers (52% for drivers aged 50 years and older). These findings have subsequently been confirmed by Horberry et al. (2004) who studied speeding, slow driving and driver characteristics among 6480 motorists in Perth, Australia. The results indicate that young drivers drove faster than middle-age and older drivers and older drivers drove more slowly than young and middle-age drivers. Women were also observed to have chosen lower speeds compared to their male counterparts.

The trend between age-related differences and speed behaviour has consistently been reported using other methods of assessment as well. Using global positioning system (GPS) and video technology, Porter & Whitton (2002) reported that young drivers adopted higher speeds, had a short deceleration distance and time as well as a shorter acceleration time than older drivers. Young drivers also incurred a substantially higher number penalty points due to speeding, while the smaller number of demerit points incurred by older drivers were owing to turning errors and violations of traffic control devices. The greater involvement of young males in speeding can be attributed to greater pressure to speed, increased exposure due to higher km's driven and potential age and gender biases on the part of arresting officers in issuing speeding citations (Shinar *et al.*, 2001).

In their study on age-related involvement patterns in fatal crashes, Zhang et al. (1998) examined the effect of crash site characteristics and fatal crashes and observed that young and elderly drivers were manifestly over-represented on roads with a speed limit of 60 km/h or lower than middle-aged drivers. Compared to middle-aged drivers, the risk of initiating a fatal crash on roads with urban speed limits was 24% higher for young drivers and 28% higher for elderly drivers. Roads with a speed limit of 70-100 km/h showed the greatest number of fatalities, 68% for young drivers, 73% for middle-aged drivers and 68% for elderly drivers (Zhang *et al.*, 1998). Young and elderly drivers' increased risk on urban roads may be related to exposure since short distance and local travel patterns are commonly associated with these driver groups than middle-aged drivers. The latter group tends to drive more on highways for work-related travel and thus demonstrate higher risk on these types of road layouts. Nevertheless, drivers across all age groups experience substantial risk when travelling on high-speed roads.

2. Perceptual factors

Drivers may also speed unknowingly. This occurs when drivers underestimate the speed at which they are travelling. Speed is determined by the optical flow rate in the peripheral visual field. At night, the peripheral vision is narrowed and consequently, little peripheral visual information available (Edquist, Rudin-Brown & Lenné, 2009). By increasing the visual flow rate, the information density of the road environment increases and drivers have greater uncertainty about the road ahead. This uncertainty is expected to lead to drivers adapting to the information flow rate by reducing their speed to manage and respond to any hazards in the roadway (Edquist *et al.*, 2009).

3. Road-related factors

a) Street lighting

Road lighting is undoubtedly, a powerful and useful traffic crash countermeasure. It has been reported to have tremendous crash-reducing effects for drivers (Beyer & Ker, 2009a) and particularly, for pedestrians at night (Wanvik, 2009a). Road lighting improves visibility, the driver's visual capabilities at night (enhances visual acuity and visual discrimination ability) and the ability to react to roadway hazards in time. However, road lighting can also have an adverse effect on drivers as they tend to use the advancements in road luminance at night time as an opportunity to increase their speed. In their investigative study on how drivers respond in terms of speed behaviour when road lighting is introduced, Assum *et al.* (1999) reported that average speeds increased by approximately 5% on unlit road sections following road lighting was installation. Cornwell (1972) also found an increase in average speed on roads with street lighting and a reduction on roads without street lighting.

b) Speed limits

Speed limits play a significant role in influencing driver speed choice. Signs are one of the many factors motorists take into account when determining an appropriate safe speed. Drivers take their cues regarding safe speed from posted speed limits. The extent to which they comply with the speed limit varies depending on the credibility and reasonableness of the speed limit in light of the road and road environment characteristics, the driving context and the driver's own characteristics and needs (OECD, 2006; Shinar, 2017). A mismatch between the posted speed limit and the (implicit) message of the road environment can directly or indirectly cause drivers to drive above the speed limit.

Speed limits denote the authorized, allowable and safe speed on a particular road. Speed limits are posted to protect the public by informing drivers of the authorized, allowable and safe speed. Most speed limits have been designed for roads under normal conditions but do not take into account poor visibility conditions due to darkness. While the posted speed limit is the maximum legal speed it may not be the maximum speed that is safe during night time conditions.

Although the visibility of the road environment changes drastically at night, in most cities and towns, speed limits remain the same. In South Africa, as elsewhere, no roads currently have night time speed limits which mean that drivers observe the same speed limit for night and daytime conditions even though the driving environments are different. By maintaining the same speed limit during day and night time conditions even though the visibility conditions are vastly different, the road environment vis-à-vis speed signs do not reflect any special danger, warning or convey any caution to drivers that they need to reduce their speed in order to see and react to traffic hazards (Leibowitz *et al.*, 1998). In fact, the speed limit could be encouraging the driver to drive at speeds that do not allow for sufficient visible distance since it conveys a sense of safety to the driver that may result in drivers feeling justified in adopting speeds that approximate the speed limit and higher. Thus the legal speed limit can also fall short of its aim of ensuring that drivers choose appropriate and safe speeds. The uniformity of speed limits for day and night time in most traffic environments can have a sanctioning effect on speed choice and provides insight into the lack of variation observed between speeds during daylight and darkness.

4. Traffic and environmental factors

a) Traffic volumes

The rate of speeding also varies according to the time of day. Excess speed variation during day and night time can be attributed to the lower traffic volumes occurring at night. In France, it was reported that higher speeds more prevalent during hours of the day when the traffic is more fluid (OECD, 2006). Table 2-6 below shows the average speed, percentage of drivers above the speed limit and the percentage of drivers that adopted speeds of 10% or more above the speed limit for passenger vehicles in France under day and night illumination.

Table 2-6: Levels of excessive speed in France for passenger cars in 2003

		Motorways (130 km/h)	In cities (50 km/h)	Main highways (90km/h)	Main highways through villages (50 km/h)
• Average speed	**Day**	124 km/h	50 km/h	85 km/h	57 km/h
• Percentage of drivers above speed limit	**Day**	42%	47%	38%	72%
• Percentage of drivers 10% or more above speed limit	**Day**	22%	17%	17%	35%
• Average speed	**Night**	114 km/h	54 km/h	88 km/h	63 km/h
• Percentage of drivers above speed limit	**Night**	37%	62%	44%	85%
• Percentage of drivers 10% or more above speed limit	**Night**	26%	27%	23%	55%

Source: OECD (2006)

With the exception of motorways, higher speeds occur predominantly more at night time than daytime. While average speeds during the day and night time are very similar on main highways, the rate of speeding at 10 km/h or more above the speed limit is 23% at night and 17% during the day.

Bester and Geldenhuys (2007) also observed a tendency among drivers to choose higher speeds when traffic volumes were lower at night. The average speeds at night (08:00 PM - 06:00 AM) recorded among South African motorists in 2000 and 2005 for different lane groups are presented in Table 2-7.

Table 2-7: Speed comparisons per annum and at night time (km/h)

Year	Two-lane		Four-lane		Six-lane	
	All	Night	All	Night	All	Night
2000	90.7	85.1	95.8	89.5	97.5	97.3
2005	90.8	85.5	92.9	88.1	95.4	96.0

Adapted from: Bester & Geldenhuys (2007)

One two-lane roads, speeds at night increased and on four- and six-lane roads, speeds decreased. This trend is similar to the trend observed for overall speeds on road types. When compared to overall speed, on two- and four- lane roads the night time speeds are approximately 5 km/h lower than the overall speed. However, on six-lane roads average speed at night time is almost the same and sometimes even higher than as the overall speed. At night time less congestion is expected and drivers may use low-volume roads as an opportunity to select higher speeds. The higher average speeds observed at night on highways and six-lanes roads relative to urban and residential roads by Bester & Geldenhuys (2007) and OECD (2006), indicate that drivers choose higher speeds when traffic volumes is more fluid.

5. Law enforcement

The degree of compliance with the speed limit results is based on a combination of drivers' appraisals of both the benefits of speeding (shorter travel time, sensation of speeding, etc.) and the perceived threat of speeding (fear of penalisation, crash risk, etc.) Law enforcement at night time can deter speeding through speed cameras and the presence of police officers. However, the RTMC has previously noted that no traffic policing is present on South African roads between the hours of 07:00 PM and 06:00 AM (News24, 2012). Without effective law enforcement, drivers are able to speed without fear of punishment and are therefore more likely to engage in speeding at night.

2.9 Pedestrian detection at night

Walking is a prevalent mode of transport globally, and especially so within South Africa. According to the Global Status Report on Road Safety 2015 (World Health Organisation, 2015) in Africa, 43% of traffic deaths occur among non-motorised users. Pedestrians account for the highest number of road user fatalities and have consistently been implicated in the high crash and mortality rates that characterise the road safety landscape in South Africa. Annually, pedestrian deaths account for approximately 45% of all traffic crashes in South Africa, with 4500 pedestrian being killed and 26 000 more injured (Brysiewicz, 2001). In 2015, the number of pedestrian deaths was 40.1%, while the number of fatalities for drivers and car occupants was 27% and 32%, respectively (RTMC, 2016). In addition to increased traffic exposure, the difference in the distribution of road user mortality can be attributed to the fact that pedestrians are traffic participants that have the least protection in the event of a crash and are therefore more likely to sustain severe injuries or fatalities. They lack the physical protection of an external hard shell and vehicle safety features such as airbags and seatbelts that are awarded to motorists and passengers.

While this study is primarily aimed at understanding drivers' behaviour at night, it was deemed important to study pedestrian detection at night since a high number of crashes at night involve pedestrians.

2.9.1 Pedestrian crash risk at night

Despite the lower exposure of pedestrians at night, most pedestrian crashes occur during hours of darkness compared to daylight (Goodwin and Hutchinson, 1977 cited in Shinar, 2007). Fatal pedestrian crashes are overrepresented at night with more than half of all pedestrian fatalities occurring during darkness. Pedestrians have a higher risk of being involved in a crash at night time. A study by Sullivan and Flannagan (2002) investigating the effect of ambient light on pedestrian crashes and vehicle crashes using the changeover in daylight savings time (DST), illustrated pedestrian vulnerability at night time. According to this study, pedestrians are up to 7 times more vulnerable in the dark and pedestrian fatal crashes are up to 4 times more likely in dark periods of daylight savings transition.

2.9.2 Factors affecting pedestrian detection at night

While fatigue and alcohol impairment are factors that rank highly on the list of factors contributing to night time crashes, the primary cause of pedestrian crashes at night can be attributed to the reduced visibility of pedestrians in traffic. Poor street lighting, the presence of glare from opposing traffic and the limited lighting afforded by the vehicles headlights all contribute to the difficulty of recognising and reacting to pedestrians from a safe distance at night (Shinar, 2017). Furthermore, pedestrians also contribute to their invisibility and high crash rates at night by overestimating their conspicuity in traffic (they have been reported to estimate their visibility nearly three times as much as the actual visibility) (Allen et al., 1970) and this is typically manifested in negligent behaviour such as wearing non-reflective clothing, crossing roadways at arbitrary locations and subscribing to the belief that the onus for detecting pedestrians at night solely rest on drivers. While both parties hold considerable influence in avoiding a crash at night, taking into consideration that pedestrians are likely to overestimate their visibility to oncoming drivers and behave in a manner that reinforces their invisibility at night, the burden of avoiding a crash more greatly rests on motorists to drive defensively and take additional precautions.

However, drivers' experience considerable difficulty in seeing pedestrians in darkness and late detection is a common experience among drivers at night (Rumar, 1990). Delayed detection leads to shorter detection distances and smaller reaction times which increase the likelihood of a crash with a pedestrian. In order to understand why drivers fail to recognise pedestrians, it is worthwhile considering the variables that affect the ability to see an object at night. According to Shinar (2007), an object's visibility is composed of its conspicuity (the state or quality of being clearly visible and discernible from its surroundings) and its detectability (the ease of which an object can be perceived once an observer is aware of its location). The detectability of a pedestrian is influenced by illumination, reflectance and contrast and the conspicuity of a pedestrian is influenced by expectancy and motion. Additional factors such as the age of the driver and the travelling speed of the vehicle also affect detection. The effects of these factors on pedestrian safety at night are reviewed below.

a) Effect of roadway illumination

Detecting pedestrians is an important task that drivers have to perform successfully in order to minimise pedestrian crashes. Decreased visibility at low illumination levels is one of the primary reasons that undermine pedestrian detection at night (Owens & Sivak, 1996). Adequate road lighting is crucial to increasing pedestrian visibility at night. Overhead lighting has been reported to elongate the distance at which pedestrians are detected (Bhagavathula et al., 2012; Edwards & Gibbons, 2008) and decrease the risk of pedestrian crashes (Wanvik, 2009). Several other studies have demonstrated that the installation of street lighting above pedestrian crosswalks can reduce crashes with pedestrians by up to 50% (Beyer & Ker, 2009b; Elvik, Høye, Vaa & Sørensen, 2009). Owens, Wood, & Owens (2007) studied the effect of reduced illumination on speed, lane keeping ability and visual recognition of pedestrians at night and reported that the likelihood of pedestrians being identified was poorer (pedestrians were detected only 29% of the time) under low lighting.

b) Effect of pedestrian luminance and contrast

While there are a variety of factors that influence pedestrian crashes, the primary cause of pedestrian crashes at night can be attributed to their low visibility in darkness. Many studies have highlighted that reduced visibility on the part of pedestrians is a major contributor to night-time pedestrian fatalities. Pedestrian contrast has a dramatic effect on the recognition of pedestrians by drivers. Many studies have corroborated that pedestrian luminance (amount and intensity of light emitted from pedestrian to approaching driver) increases pedestrian detection at night time and shortens the time and distance it takes to recognise pedestrians in the roadway (Allen *et al.*, 1970; Balk, Tyrrell, Brooks & Carpenter, 2008; Shinar, 1985). In some studies it has been reported that with a dark-clad pedestrian under high and low beam visibility conditions, the use of a retroreflective tag resulted in a two-fold increase in the pedestrian visibility distance (Shinar, 1984). Other studies have shown that when pedestrians wore black clothing they were recognised on 52.5% of the younger drivers circuit laps and only on 15% of the older drivers circuit laps (Wood *et al.*, 2005). Conversely, when wearing white clothing, pedestrians were recognised on 97.5% of the younger drivers' circuit laps and 70% on the older drivers' circuit laps. The same study also reported that response distances by older drivers under high-beam conditions increased by a factor as much as 25.

However, merely adding a retroreflective vest on black clothing does not significantly increase pedestrian conspicuity. It is only when the retroreflective material was positioned on the major, movable joints (such as the elbows, wrists, ankles and knees) in a manner that depicts biological motion (biomotion) that the effect of retroreflective material was greater than that of white clothing (Wood et al., 2005 and Balk et al., 2008). This is because marking the pedestrian's extremities capitalises on the sensitivity of our visual system and perceptual abilities to visually recognise dynamic objects than static ones. Figure 2-24 demonstrates the different marking patterns of pedestrian clothing with pedestrian number 1= darkly-clad pedestrian, pedestrian number 2 = retro-reflective vest, pedestrian 3 & 4= retroreflective straps on ankles and wrists, pedestrian number 5= retroreflective straps on ankles, wrists, knees, elbow and shoulders.

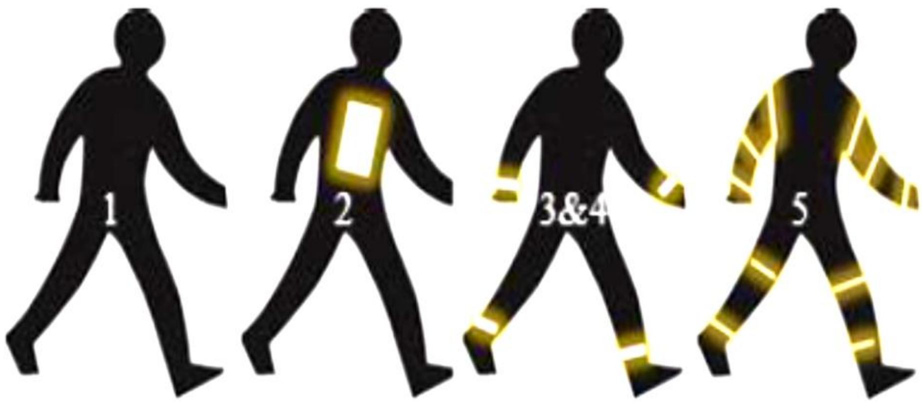


Figure 2-24: Frontal view of the different pedestrian clothing configurations

Source: (Balk *et al.*, 2008)

There is overwhelming research evidence that support the effectiveness of biomotion clothing in enhancing pedestrian conspicuity at night. When pedestrian detection at night was analysed in relation to black, white, retroreflective and biomotion pedestrian clothing, recognition was 33.8% for black clothing, 63.8% for retroreflective clothing, 83.8% for white clothing and 93.8 % for biomotion clothing (Wood *et al.,* 2005). The utility of biomotion clothing at night was also demonstrated by Wood et al. (2014) who reported that both young and older drivers were able to recognise all pedestrians who wore the biomotion configuration in the absence of glare. Across all driver age groups, the mean recognition distances for biomotion-clad pedestrian (249.0 m) were almost twice as long as that of pedestrians that wore the standard reflective vests (131.7 m). Response distances for the biomotion condition also increased by a factor of 50 compared to black clothing. This is also consistent with other research that showed that pedestrians wearing biomotion are consistently recognised more frequently and at longer distances at night (Tyrrell et al., 2009, Owens et al., 1994 and Balk, 2007).

Furthermore, it should be noted that increased object recognition goes beyond mere anticipation and requires the driver having additional *a priori* information on what certain features of the object detected represent. Muttart et al. (2016) confirmed these findings in their study on the influence of driver expectation on target recognition at night. The results show that drivers were more likely to decipher the location of the light source (lighted ball) when they were cognisant of what the light source embodied. This is because drivers' perceptually attached the light to a location that was more sensible to them (suspended in the air in the roadway vs on the side of the road). Thus, in the context of biological motion configuration it is vital that that drivers are cognisant of the fact that retro reflective markers represent pedestrians (Shinar, 1985).

c) Effect of motion

The visual world of the driver is in constant motion. Dynamic targets are more likely to be detected than static targets. This is because our visual system and perceptual abilities is sensitive to visually recognising dynamic objects better rather than static ones. In their study on the effect of expectancy and pedestrian detection distances for mobile and static pedestrians, Bhagavathula & Gibbons (2013) reported that when expectancy was low, moving pedestrians were detected 94.44% of the time and static pedestrians were detected 88.33% of the time. In high expectancy phases, moving pedestrians were detected 50% of the time, static pedestrians were detected 56.25% of the time and moving pedestrians with a yellow non-retroreflective helmet was detected 61.64% of the time. However, overall detection distances indicate that the effect of motion of an object almost halves the detection distance for static objects (mean distance of 68.29 m) relative to moving pedestrians (mean distance of 135.34 m).

d) Effect of expectancy

Throughout the human lifespan, knowledge; based on experience and interaction with the environment is constantly accumulated and stored in a bank of knowledge. This knowledge is based on a pattern of regularity observed in the world. As we become accustomed to our surroundings we expect a certain degree of consistency and uniformity when we find ourselves in similar settings. This phenomenon is characterised as expectancy and is a crucial factor in driver safety. Regular experience in the traffic environment with road infrastructure and facilities, interaction with motorised and non-motorised road users and under varying weather and roadway conditions leads to the development of mental stereotypes of roads and driving and creates within the driver the expectation of a certain degree of consistency and normality when driving in similar road conditions. Using this pre-existing experiential knowledge about the road environment, the driver makes predictions about the probability of certain events transpiring and plans the necessary manoeuvres to be enacted should these events be realised which changes behaviour.

Given the substantial role that expectancy plays in anticipating potential incidents in the traffic environment and formulating a suitable response ahead of the incident, it is to be expected that this factor plays a major role in detecting pedestrians at night. Driver expectation affects the perception and detection of objects under night time conditions in numerous ways. Detecting an unexpected object requires that the object have a high degree of conspicuity in order to attract the drivers attention. Conversely, detecting an expected object involves directing visual attention to only detecting the objects most salient visual properties (Shinar, 2017). When a driver anticipates a pedestrian on the road, the visual field is alerted to finding the object and the attentional mechanisms are primed to identifying the most salient features of a pedestrian such as the physical features of the pedestrian. In addition to anticipating a pedestrian in the roadway, familiarity with the pedestrian (child vs adult pedestrian) and knowledge on the probable location and position of the pedestrian are additional details that can narrow down the visual search and allow the driver to concentrate on particular stimuli and in so doing, accelerate the detection process (Shinar, 2017).

The effect that expectancy has on pedestrian detection distances at night has been recognised by numerous studies and as early as 1938 in the literature. Using a pedestrian dummy as a test target while participants travelled on an unlit rural road, Roper and Howard (1938) reported a 2:1 ratio between drivers who expected pedestrians and drivers who did not expect pedestrians in darkness. These results imply that under night time conditions, an expected object will be seen at twice the distance as that of an unexpected object. For example, an expected object that is detected at 100 m will only be detected at 50 m for an unexpected object. Although no subsequent studies have reported similar ratios, several studies have affirmed the importance of expectancy in enhancing pedestrian detection in darkness. In his study on his study on pedestrian visibility at night time under various combinations of driver expectancy and pedestrian clothing characteristics on an unlit rural road, Shinar (1985) observed that pedestrian visibility distance is directly proportional to expectancy and that this effect is further magnified for pedestrians with a retroreflective tag (Shinar, 1985).

Bhagavathula & Gibbons (2013) examined the combined effect of expectancy, motion and overhead lighting on pedestrian visibility in darkness using a more vigorous methodology. Participants were required to identify new and old static and moving objects as they navigated a test-track in the presence and absence of overhead lighting. The objects that featured in the experiment were objects' drivers typically encounter on a roadway at night such as deer and pedestrians, participants were told that they may or may not encounter these objects, prior to the experiment and were also given a chance to familiarise themselves with the objects during the practise laps on the test track. The experimental laps consisted of a detection lap and a recognition lap in which participants were asked to identify every object present and announce this to the in-vehicle experimenter who recorded the responses and calculated the detection distances thereafter. Detection laps were characterised as the low expectancy phases where drivers detected every object (moving pedestrian, static pedestrian and static deer) on the test track. Following this was the recognition lap which was characterised as the high expectancy phase and included actively searching for a specific object (moving pedestrian with yellow, non-reflective helmet) while still trying to detect the other three objects that were in the detection lap.

Detection distances were substantially longer for high expectancy laps (mean of 111.51 m) than low expectancy laps (mean of 87.47 m) and this was consistently reported despite object type, motion and driver age. Moreover, the greatest increase in detection distance was observed for moving objects. During the high expectancy lap, percentage detection for moving pedestrians was higher than deer and static pedestrians. In addition, the mean pedestrian detection distance increased by 48.91 m relative to the lower expectancy phase for moving pedestrians, which translates into a 41.12 % increase in mean detection distance. However, detection distances for moving pedestrians were greater than that of moving pedestrian with yellow, non-retroreflective helmet which in turn was only slightly higher than that of static pedestrians. The authors attribute this counter-intuitive and insignificant statistical difference to the effect of motion on object detection distance as a function of expectancy. Given that every object had an equal opportunity of being recognised in the high expectancy lap, the sustained identification of moving pedestrians at longer detection distances relative to moving pedestrian helmet and static pedestrians illustrates that motion is substantially more influential in attracting attention than expectancy when participants are actively searching for new objects.

e) Effect of driver age

Pedestrian detection at night varies as a function of driver age. Wood, Lacherez, & Tyrrell (2014) investigated the effect of driver age on pedestrian recognition distances at night while participants drove along a closed road circuit and were instructed to identify pedestrians wearing biomotion clothing or a high visibility reflective jacket. At an approach speed of 60 km/h, the mean detection distances at which pedestrians were recognised by older drivers (129.1 m) was almost double the distance for younger drivers (251.5 m). These findings are particularly profound given that these recognition distances were recorded for pedestrians wearing biological motion reflective clothing. Similar results were obtained by Wood et al. (2005) when examining pedestrian recognisability under low-beam and high-beam illumination, different clothing configuration (white, black, retroreflective and biomotion clothing) and in the presence and absence of glare. Overall, pedestrian recognition capacity is significantly worse for older drivers than young drivers with younger drivers recognising 84.4% of pedestrians (94% in the absence of glare and 75% in the presence of glare) and older drivers recognising 53.2% of pedestrians (59% in the absence of glare and 48% in the presence of glare). Even when driver expectancy is increased, younger drivers still outperform older drivers in recognising pedestrians at longer distances (Bhagavathula & Gibbons, 2013).

Poorer pedestrian detection among older drivers may be attributed to age-related changes in visual and motor function. Older drivers commonly report difficulties with visibility at night, tend to experience poorer eye health and have slower motor function associated with aging, which translates into increased time to press the brake pedal in response to a pedestrian in the roadway (Owsley, 2004). It is therefore to be expected that pedestrian recognition capacity at night is significantly worse for older drivers than younger drivers.

f) Effect of driver speed

The primary cause of pedestrian-vehicle crashes at night is late detection. Most of the time, drivers do not see a pedestrian until the vehicle is a few metres away from the pedestrian or almost passing alongside the pedestrian. Shinar (2007) attributes the late detection of pedestrians to drivers over-driving the visibility distance afforded by the vehicle's headlights. This means that the speed at which the vehicle is travelling is too fast compared to the visibility distance needed to detect a pedestrian in time. Figure 2-25 demonstrates the relationship between speed and drivers' visual field. As speed increases, drivers' field of vision progressively decreases. At 40 km/h, the drivers' visual field is expansive enough for drivers to detect pedestrians in the peripheral view. At 100 km/h, the horizontal visual field is severely narrowed and covers less than 50°, which considerably reduces drivers' ability to assess prospective hazards. Fundamentally, higher speeds undermine the drivers' ability to detect and react to pedestrians crossing in the periphery.

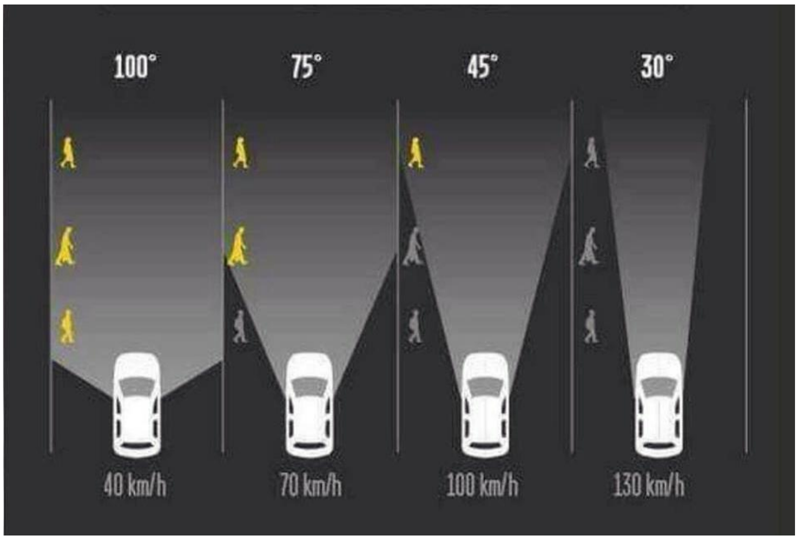


Figure 2-25: Drivers' visual field as a function of speed in detecting pedestrians

Source: OECD (2006)

When drivers overdrive their headlights, they detect and react to pedestrians at shorter distances and consequently lack sufficient time to avoid impending collision. For example, using a reaction time of 1.0 s on a dry road with low beam illumination, 50 metres is required in order to detect a pedestrian, apply brakes and come to a complete stop safely. However, drivers usually detect pedestrians at an average distance of 35 m (Leibowitz *et al.*, 1998). Reaction time and visibility is further diminished on a wet road and in the presence of glare from oncoming traffic. It has been postulated that among other factors, drivers overdrive their headlights at night because they misjudge speed and visibility distances and that this is caused by a lack of awareness of visual limitations during darkness (Leibowitz *et al.*, 1998).

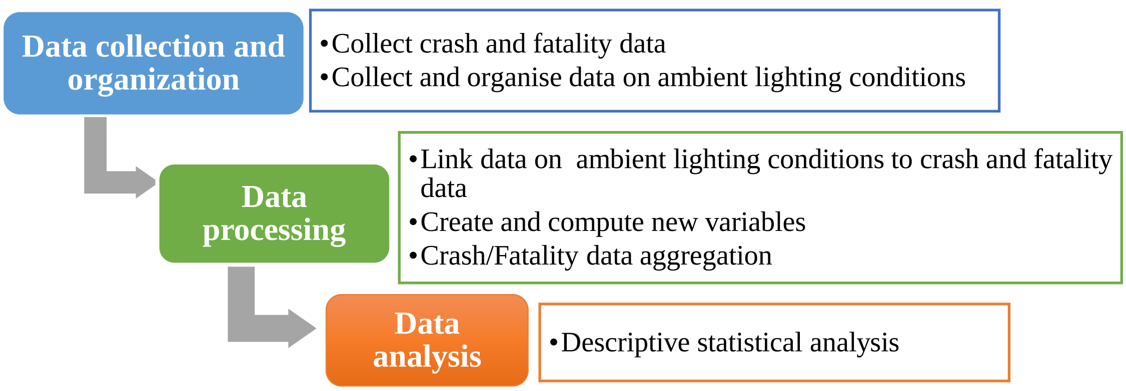
Chapter 3: Methodology

3.1 Introduction

This chapter discusses the research design and method adopted in this study. Detailed descriptions of each data source and data collection method are provided along with a description of the different variables used to answer the research questions.

A number of sources and methods were used to collect data for this study. These sources include crash and fatality data, naturalistic driving videos and surveys. Crash and fatality data and naturalistic driving videos are both secondary sources of data that were used in this study. Surveys are the only primary source of data used in this study. Given that the central purpose of this study is to explore driver behaviour at night, it was decided to integrate data from various sources as crash data, fatality data, naturalistic driving video data and survey data which are all crucial to exploring driver performance at night time. In addition to this, the function of this integration will provide a nuanced understanding of night time driving in South Africa, augment our understanding of the factors contributing to the magnitude of night time casualties and also help explain the findings generated by each method of data collection or data source.

3.2 Crash and fatality data collection and organisation



3.2.1 Road traffic crash dataset

This study examined the composition of road traffic crashes in the City of Cape Town from 2006-2015. The dataset of road traffic crashes (RTC) used in this analysis comprises 766,554 police-reported crashes that occurred in the City of Cape Town between 2006 and 2015. The crash data was obtained from the City of Cape Town's Transport and Urban Development Authority with permission to use the datasets in this study. The crash data was obtained in an Excel format and the information collected on RTC's includes 23 variables arranged in columns. A list of these variables is provided below:

- Authority code
- Accident reference number
- South African Police Services (SAPS) case number
- Suburb of crash occurrence
- Sub-area
- Road name
- Road description
- Node description
- Km marker
- Police station
- Day of week
- Accident time
- Obstructions
- Accident type
- Specified cause of accident
- Vehicle type
- Number of drivers involved in the accident
- Number of passengers involved in the accident
- Number of pedestrians involved in the accident
- Number of fatal injuries
- Number of serious injuries
- Number of slight injuries
- Number of no injury cases

3.2.2 Fatal injury dataset

A dataset of 7,591 road traffic fatalities (RTFs) that occurred in the City of Cape Town between 2007 and 2016 was also used. This data was accessed from Forensic Pathology Services was provided by The City of Cape Town's Transport and Urban Development Authority. The data comprises 12 variables provided in the list below:

- Date of injury
- Time of injury
- Gender of the victim
- Racial category of the victim
- Age of the victim (in years)
- Scene of injury
- Suburb of injury
- Nearest South African Police Services (SAPS) station
- Vehicle type
- Alleged cause of fatality
- Incident street
- Incident suburb

3.2.3 Ambient lighting conditions dataset

Once the crash and fatal injury datasets were obtained, it was necessary to combine this data with a data set containing information on ambient lighting conditions to accurately determine periods of daylight and darkness and match these with crash and fatalities data. Two methods of obtaining data on ambient lighting conditions were considered. These methods are described below.

a) Classification according to time of day

The first method entailed classifying crashes according to pre-defined categories of day and night time. Daytime would be classified as the period of 06:00 AM - 05:59 PM and night time would be classified as the period of 06:00 PM - 05:59 AM. All crashes and fatal injuries occurring between 06:00 AM - 05:59 PM would be classified as daytime crashes and all crashes occurring between 06:00 PM - 05:59 AM would be classified as night time crashes. This method was deemed unfavourable since it does not account for seasonal changes which affect the duration of external lighting periods. The second method of classifying crash data according to periods of daylight and darkness was therefore selected.

b) Classification according to ambient light condition

The second method entailed classifying crashes according to the type of ambient illumination that was available during the time of the crash. Ambient illumination refers to the amount of external lighting that exists naturally in an environment before the addition of artificial lighting such as overhead street lighting and vehicle lighting. Sunlight is a prime example of ambient lighting.

Contrary to what may be observed when looking at the sun, the variation of light from daytime to night time in a 24 hour day does not only consist of periods of light and darkness. Depending on the solar elevation angle, ambient light can be categorised into three categories: day, night and twilight. Twilight is the time of day before sunset or sunrise, in which the atmosphere is partially illumined by the sun. At this period of the day the sky is neither completely dark nor completely lit. There are three established and widely accepted subcategories of twilight: civil twilight (brightest), nautical twilight and astronomical twilight (darkest) and these phases occur during the day and night. Figure 3-1 shows the difference between civil, nautical and astronomical twilight. Full descriptions of these phases are provided below.

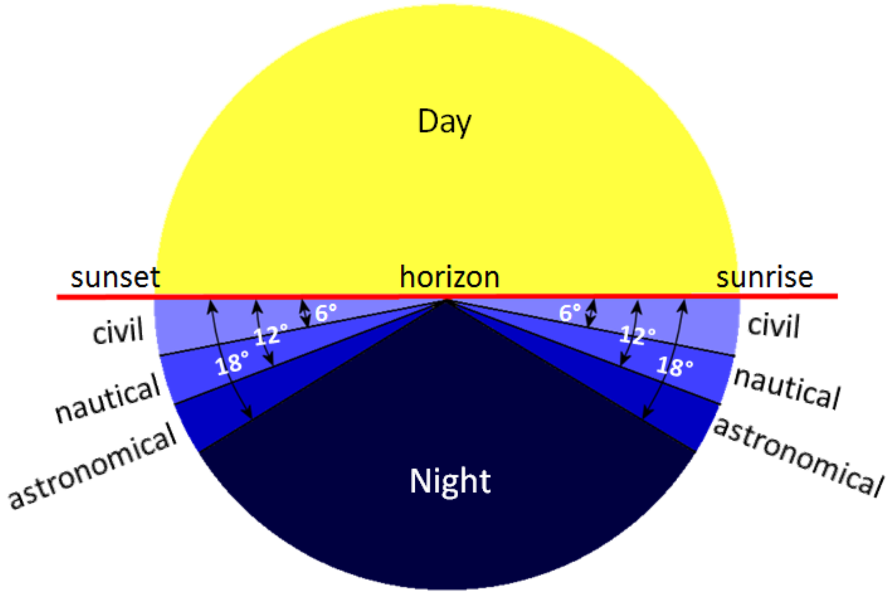


Figure 3-1: Description of ambient illumination conditions and different stages of twilight

Source: Boyce (2003)

Day: Often characterised as the time period between sunrise and sunset, this is the period when the sun is 18 to 25 degrees above the horizon and illuminates the sky (Boyce, 2003). This is the period when the sky is the brightest and drivers are expected to feel no discomfort due to lack of light or the low angle of the sun.

Night: Often characterised as the period between dusk and dawn, this is the period when the sun reaches 18 to 90 degrees below the horizon and no longer illuminates the sky (Boyce, 2003). Technically, it is the period between the end of evening astronomical twilight and the start of morning astronomical twilight. However, evening and morning astronomical twilight may also be considered as night time since significantly less illumination is available and drivers depend on artificial illumination such as street lights and vehicle headlights to see the road environment.

Civil twilight (morning): Also known as dawn, this is the period when the sun is six degrees below the horizon (Boyce, 2003). Morning twilight takes place approximately 30 minutes before sunrise and ends at sunrise. In the absent of fog or other adverse weather conditions, this period provides enough illumination for motorists to drive without requiring their headlights.

Nautical twilight (morning): The period when the sun is between six and twelve degrees below the horizon (Boyce, 2003). During this period, artificial illumination may be required when driving.

Astronomical twilight (morning): The period when the sun is between twelve and eighteen degrees below the horizon (Boyce, 2003). The sky's illumination during this period is so dim that it is often regarded as night time and artificial lights must be activated.

Civil twilight (evening): Also known as dusk, this is the period between sunset and the moment the sun is six degrees below the horizon (Boyce, 2003). Evening twilight begins at sunset and lasts approximately 30 minutes. This period provides sufficient illumination for motorists to continue driving without the need for artificial lighting from street or vehicle lights.

Nautical twilight (evening): The period when the sun is between six and twelve degrees below the horizon (Boyce, 2003). During this period, street lights are lit and motorists begin using headlights

Astronomical twilight (evening): The period when the sun is between twelve and eighteen degrees below the horizon (Boyce, 2003). At this point there is very little light in the sky but it is not yet completely dark. Once astronomical twilight is at eighteen degrees below all stars in the sky will be visible.

It was deemed important to categorise crashes and fatalities according to the ambient light condition at the time of the incident instead of using pre-defined hours of day and night time. This was resolved for two reasons. Firstly, ambient illumination during morning and evening periods varies significantly not only across seasons but also across weeks and days (albeit to a lesser extent). Simply using the hours of the day (i.e. using 06:00 AM-17:59 PM as daytime and 18:00 PM -05:59 AM as night time) and generalising these to all days even when night or daytime time may fall outside of these pre-determined periods, introduces errors when conducting a comparative analysis of crashes occurring during day and night time. This undermines the results obtained from crash and fatality analysis. To maintain the validity of the results, it was therefore determined to classify crash and fatality data by light conditions rather than time of day. Secondly, classifying crash and fatalities according to light condition enables an analysis of incidents that occur not only during day and night time periods but also during twilight. This analysis adds a more nuanced view of crash vulnerability in differing lighting conditions.

3.2.3.1 Processing data on ambient lighting conditions

Data on ambient lighting conditions for crash and fatality data in Cape Town was collected from the website Time and Date AS (Time and Date AS, n.d.). Time and date is a Norwegian-based reference website that supplies free current and historical data on time, weather, sun and moon positions all over the world. Of particular interest are the sunrise, sunset and twilights timetables as shown in Figure 3-2. Daily information on lighting conditions according to time of day in a particular year was accessed online (Time and Date AS, n.d.) and this includes data on the following variables:

- Date (day, month, year)
- Times of sunrise and sunset
- Day length
- Start and end times of astronomical twilight
- Start and end times of nautical twilight
- Start and end times of civil twilight

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Sun & Moon Today | Sunrise & Sunset | Moonrise & Moonset | Moon Phases | Eclipses | Night Sky Beta

August 2010 — Sun in Cape Town

Month: August Year: 2010 Go

2010	Sunrise/Sunset		Daylength		Astronomical Twilight		Nautical Twilight		Civil Twilight		Solar Noon	
Aug	Sunrise	Sunset	Length	Difference	Start	End	Start	End	Start	End	Time	Mil. km
1	07:38 (69°)	18:06 (291°)	10:27:40	+1:30	06:12	19:32	06:42	19:03	07:12	18:33	12:52 (38.1°)	151.833
2	07:38 (69°)	18:07 (291°)	10:29:12	+1:31	06:12	19:33	06:41	19:03	07:11	18:33	12:52 (38.4°)	151.815
3	07:37 (69°)	18:08 (291°)	10:30:45	+1:33	06:11	19:33	06:41	19:04	07:10	18:34	12:52 (38.6°)	151.796
4	07:36 (70°)	18:08 (290°)	10:32:19	+1:34	06:10	19:34	06:40	19:04	07:10	18:35	12:52 (38.9°)	151.777
5	07:35 (70°)	18:09 (290°)	10:33:55	+1:35	06:10	19:35	06:39	19:05	07:09	18:35	12:52 (39.2°)	151.757
6	07:34 (70°)	18:10 (290°)	10:35:32	+1:37	06:09	19:35	06:38	19:06	07:08	18:36	12:52 (39.4°)	151.736
7	07:33 (71°)	18:10 (289°)	10:37:10	+1:38	06:08	19:36	06:37	19:06	07:07	18:37	12:52 (39.7°)	151.714
8	07:32 (71°)	18:11 (289°)	10:38:50	+1:39	06:07	19:36	06:36	19:07	07:06	18:37	12:51 (40.0°)	151.692
9	07:31 (71°)	18:12 (289°)	10:40:31	+1:40	06:06	19:37	06:36	19:08	07:05	18:38	12:51 (40.3°)	151.668
10	07:30 (72°)	18:12 (288°)	10:42:12	+1:41	06:05	19:37	06:35	19:08	07:04	18:38	12:51 (40.6°)	151.644
11	07:29 (72°)	18:13 (288°)	10:43:55	+1:42	06:04	19:38	06:34	19:09	07:03	18:39	12:51 (40.9°)	151.619
12	07:28 (72°)	18:14 (287°)	10:45:39	+1:44	06:04	19:39	06:33	19:09	07:02	18:40	12:51 (41.2°)	151.594
13	07:27 (73°)	18:15 (287°)	10:47:25	+1:45	06:03	19:39	06:32	19:10	07:01	18:40	12:51 (41.5°)	151.567
14	07:26 (73°)	18:15 (287°)	10:49:11	+1:46	06:02	19:40	06:31	19:11	07:00	18:41	12:51 (41.8°)	151.540

Figure 3-2: Data on day, night and twilight periods for Cape Town

Source: Time and Date AS (n.d.)

The classification of the data by light condition was developed based on the daily time of sunrise, time of sunset, and the officially defined civil twilight that the website provides. Using this data, a dataset comprising daily data on lighting conditions was constructed for a period between 2006 and 2016. The dataset includes the following variables:

- Date
- Day length
- Start time of morning astronomical twilight
- Start time of morning nautical twilight
- Start time of morning civil twilight
- Sunrise time
- Sunset time
- End time of evening civil twilight
- End time of evening nautical twilight
- End time of evening astronomical twilight

- Duration of morning astronomical twilight
- Duration of morning nautical twilight
- Duration of morning civil twilight
- Duration of evening astronomical twilight
- Duration of evening nautical twilight
- Duration of evening civil twilight

Collectively, eight different conditions of light were classified according to the data. Lighting conditions were defined as follows:

- **Day**: time interval from start of sunrise – start of sunset
- **Night**: time interval from end of evening astronomical twilight – start of morning astronomical twilight
- **Civil twilight (morning)**: time interval from start of morning civil twilight - start of sunrise
- **Nautical twilight (morning)**: time interval from start of morning nautical twilight – start of civil twilight
- **Astronomical twilight (morning)**: time interval from start of morning astronomical twilight - start of morning nautical twilight
- **Civil twilight (evening)**: time interval from start of sunset – end of evening civil twilight
- **Nautical twilight (evening)**: time interval from end of evening civil twilight - end of evening nautical twilight
- **Astronomical twilight (evening)**: time interval from end of evening nautical twilight – end of evening astronomical twilight

When analysing crash and fatality data according to different phases of ambient lighting, the eight different categories of light were retained and incidents were assigned according to these categories. However, when conducting an analysis of crashes during day time and night time, evening astronomical twilight, night time and morning astronomical twilight were combined. Even though evening and morning astronomical twilight periods are not completely dark as the night time period, it is still very dark which obstructs visibility and warrants the use of artificial illumination such as street and vehicle lights. Thus, when analysing crashes in terms of day and night time, lighting conditions were defined as follows:

- **Day**: time interval from start of sunrise – start of sunset
- **Night**: time interval from end of evening nautical twilight – start of morning nautical twilight
- **Civil twilight (morning)**: time interval from start of morning nautical twilight - end of civil twilight
- **Civil twilight (evening)**: time interval from start of sunset – end of evening nautical twilight

3.2.3.2 Linking the datasets

The road traffic crashes data set and the fatal injuries data sets were linked to the ambient lighting conditions data set. Linking the two datasets served two main purposes: (1) to link the type of ambient illumination (e.g. twilight, day-time or night-time) to the time of crash/fatal injury occurrence for each crash/fatality record and (2) to facilitate the comparative analysis of crash/fatality frequency during night-time and day-time conditions.

To link the data on ambient illumination to crash/fatality data, a VLOOKUP formula was created in the Excel sheet to perform a vertical lookup by searching for an exact match date in the column of "date of crash/fatality occurrence" and returning variables of the ambient illumination dataset in the same row once the exact match has been found. The form of the VLOOKUP function used for the data linkage is presented below:

=VLOOUP (lookup value, range containing the lookup value, the column number in the range containing the return value, FALSE)

Simply put,

- The lookup value is the date of a crash/fatality occurrence
- The range containing the lookup value is the entire table containing data on ambient illumination conditions
- The column numbers (or index) containing the return values range from 2 to 15 (i.e. all the columns in the ambient illumination datasets, except for date of crash/fatality)
- The FALSE argument is used to return an exact match from the return value

3.2.3.3 Creation and computation of new variables

Linking the datasets resulted in two datasets which consist of information on crash or fatal injury occurrence and the corresponding daily data on ambient lighting conditions. An additional variable was added to the linked datasets and this is the type of ambient illumination (i.e. twilight, night-time, day-time) during which a RTC or a fatal injury occurred. To assign the type of ambient illumination to each time of crash or fatal injury occurrence, a formula was created in Excel using a nested IF Function (or multiple IF statements). The nested IF functions consist of seven IF statements following this logic:

- If the time of crash/injury is between the start time of the morning astronomical twilight and the start time of the morning nautical twilight, return “Morn_Astronom”, otherwise,
- If the time of crash/injury is between the start time of the morning nautical twilight and the start time of the civil twilight, return “Morn_Naut”, otherwise,
- If the time of crash/injury is between the start time of the morning civil twilight and the start time of sunrise, return “Morn_Civil”, otherwise,
- If the time of crash/injury is between the start time of sunrise and the start time of sunset, return “Daytime”, otherwise,
- If the time of crash/injury is between the start time of sunset and the end time of the evening civil twilight, return “Eve_Civil”, otherwise,
- If the time of crash/injury is between the end time of the evening civil twilight and the end time of the evening nautical twilight, return “Eve_Naut”, otherwise,
- If the time of crash/injury is between the end time of the evening nautical twilight and the end time of the evening astronomical twilight, return “Eve_Astronom”, otherwise, return “Nighttime”.

The nested IF function is shown in an Excel screenshot presented in Figure 3-3.

	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB
1		Morn_Astron	Morn_Naut	Morn_Civil	Sunrise	Daytime	Sunset	Eve_Civil	Eve_Naut	Eve_Astron			
2	Time of accident	Start	Start	Start	Start	length	Start	End	End	End	Period of injury		
3	22:15	03:55	04:34	05:09	05:38	14:22:06	20:00	20:29	21:05	21:44	`=IF(AND(AP3>=AQ3,AP3<AR3),"Morn_Astronom", IF(AND(AP3>=AR3,AP3<AS3),"Morn_Naut", IF(AND(AP3>=AS3,AP3<AT3),"Morn_Civil", IF(AND(AP3>=AT3,AP3<AV3),"Daytime", IF(AND(AP3>=AV3,AP3<AW3),"Eve_Civil", IF(AND(AP3>=AW3,AP3<AX3),"Eve_Naut", IF(AND(AP3>=AX3,AP3<AY3),"Eve_Astronom", "Nighttime")))))))`		
4	04:00	03:55	04:34	05:09	05:38	14:22:06	20:00	20:29	21:05	21:44			
5	04:00	03:55	04:34	05:09	05:38	14:22:06	20:00	20:29	21:05	21:44			
6	20:30	03:55	04:34	05:09	05:38	14:22:06	20:00	20:29	21:05	21:44			
7	23:00	03:55	04:34	05:09	05:38	14:22:06	20:00	20:29	21:05	21:44			
8	23:55	03:55	04:34	05:09	05:38	14:22:06	20:00	20:29	21:05	21:44			
9	17:15	03:55	04:34	05:09	05:38	14:22:06	20:00	20:29	21:05	21:44			
10	20:30	03:55	04:34	05:09	05:38	14:22:06	20:00	20:29	21:05	21:44			
11	20:12	03:55	04:34	05:09	05:38	14:22:06	20:00	20:29	21:05	21:44	Eve_Civil		
12	07:00	03:55	04:34	05:09	05:38	14:22:06	20:00	20:29	21:05	21:44	Daytime		
13	11:25	03:55	04:34	05:09	05:38	14:22:06	20:00	20:29	21:05	21:44	Daytime		
14	00:25	03:55	04:34	05:09	05:38	14:22:06	20:00	20:29	21:05	21:44	Nighttime		
15	06:35	03:55	04:34	05:09	05:38	14:22:06	20:00	20:29	21:05	21:44	Daytime		
16	01:30	03:55	04:34	05:09	05:38	14:22:06	20:00	20:29	21:05	21:44	Nighttime		
17	01:30	03:55	04:34	05:09	05:38	14:22:06	20:00	20:29	21:05	21:44	Nighttime		
18	07:00	03:55	04:34	05:09	05:38	14:22:06	20:00	20:29	21:05	21:44	Daytime		
19	21:15	03:55	04:34	05:09	05:38	14:22:06	20:00	20:29	21:05	21:44	Eve_Astronom		
20	14:35	03:55	04:34	05:09	05:38	14:22:06	20:00	20:29	21:05	21:44	Daytime		
21	01:00	03:55	04:34	05:09	05:38	14:22:06	20:00	20:29	21:05	21:44	Nighttime		
22	06:15	03:55	04:34	05:09	05:38	14:22:06	20:00	20:29	21:05	21:44	Daytime		
23	03:00	03:55	04:34	05:09	05:38	14:22:06	20:00	20:29	21:05	21:44	Nighttime		
24	17:30	03:55	04:34	05:09	05:38	14:22:06	20:00	20:29	21:05	21:44	Daytime		
25	04:30	03:55	04:34	05:09	05:38	14:22:06	20:00	20:29	21:05	21:44	Morn_Astronom		

Multiple IF statements

Figure 3-3: Screenshot from Excel sheet displaying nested IF function used

3.3 Naturalistic driving videos

Naturalistic driving videos were also used to obtain data about driving at night time. The naturalistic driving videos used in this study are a secondary source of data accessed from the Department of Civil Engineering at Stellenbosch University for analysis. These driving videos were collected in 2014 as part of a Masters project to investigate novice driving behaviour among South Africans during daytime conditions. Although data was collected for both day and night time conditions, the data that was used in the original project was used to analyse driving behaviour during daytime conditions only. Driving videos recorded at night time were not used in the original study. As such, this study will be first one to make use of the naturalistic driving videos at night time to collect data on driving behaviour under nocturnal conditions.

3.3.1 Overview of the research instrument

Naturalistic observation, that is observing subjects in their natural environment without any external manipulation by the observer, is central to many empirical data collection endeavours and one that has in recent years, increasingly been applied in traffic safety research studies. The *Handbook of Traffic Psychology* describes naturalistic driving studies as the research technique used to gather information and insight on everyday driver behaviour by observing drivers unobtrusively in a natural driving setting for extended periods of time (Eby, 2011). Using this approach, observations of the driver, the vehicle and the surrounding traffic conditions are collected. These observations enable an analysis of the interrelationships between the driver, vehicle and traffic environment in normal situations, conflict situations and crashes which contribute substantially to understanding the processes resulting in crashes and near misses (van Schagen & Sagberg, 2012). For several months and sometimes even years, the participant's vehicle is equipped with video cameras and in-vehicle sensors and devices that capture data on driving behaviour, vehicle manoeuvres and external conditions (Winkelbauer, Eichhorn, Sagberg & Backer-Grøndahl, 2010).

While alternative methods of collecting driver behaviour exist, such as driving simulators or instrumented vehicles, these research techniques have several limitations. The primary weakness of driving simulation is that the results are not easily transferable to real-life traffic conditions and driver behaviour given that both the virtual traffic environment and vehicle characteristics are proxies of reality (van Schagen & Sagberg, 2012). Although the absence of risk when driving in a virtual driving environment is an advantage when using these techniques, it may also threaten the validity of the results. Instrumented vehicles overcome some of the disadvantages associated with driving simulators in that driving behaviour is measured while driving a real car; in real traffic. However, these experiments typically involve the presence of the researcher on board and participants are aware that they are being observed. This research instrument thus increases the Hawthorne Effect which may lead to socially desirable responses. Furthermore, in order to reduce potential risk to participants, instrumented vehicle tests oftentimes necessitate the need to divulge information about study aims, traffic conditions and the actual position or possibility of encountering other road users. This information increases driver expectation which alters behaviour and skews results since drivers in real traffic do not possess such foreknowledge when driving in similar conditions.

Naturalistic driving studies overcome these weaknesses and hold added value for road safety research. The main advantage of this technique is that it provides realistic insight into normal everyday driving which provides a much wider perspective of driving behaviour since drivers traverse more road environments than only the experiment conditions and biases are minimised (van Schagen & Sagberg, 2012). Moreover, analysing conflicts, near-misses and crashes in real time are enabled by naturalistic driving studies (Winkelbauer *et al.*, 2010).

However, it must also be acknowledged that the advantages of the naturalistic driving approach also introduces complexities in data analysis since the information collected may demonstrate correlations between particular variables and driver behaviour but not necessarily about unambiguous causal relationships (Winkelbauer *et al.*, 2010). This is due to the flexible nature of the experimental design which makes examining the associations between variables in isolation difficult since confounding variables are not controlled or eliminated.

3.3.2 Data collection equipment

The data acquisition system (DAS) used in this study was the Smarty Black Box BX4000 which was purchased from Rock Solid Industries (RSI). The DAS is an in-vehicle technology system that consists of the following components:

- An on-board computer or **data logger** that records vehicle performance data such as specific position data (GPS), vehicle speed, acceleration, deceleration and time.
- Three **video cameras** positioned at various angles:
  1) a driver-facing camera used to record data on the interior of the vehicle notably, the driver and front passenger
  2) a front-facing camera used to record data on the external road environment in the drivers forward view
  3) a rear-facing camera used to record data on the external road environment in the drivers backward view.

An external GPS linked the video recordings to the speed and location information of the vehicle. This data was stored along with the video data on the data logger. The cameras were equipped with a 4 gigabyte SD memory card and had enough capacity to ensure that the recording proceeds without failure in the event of power loss or abnormal power outages. The data acquisition system used in this study is displayed in Figure 3-4.

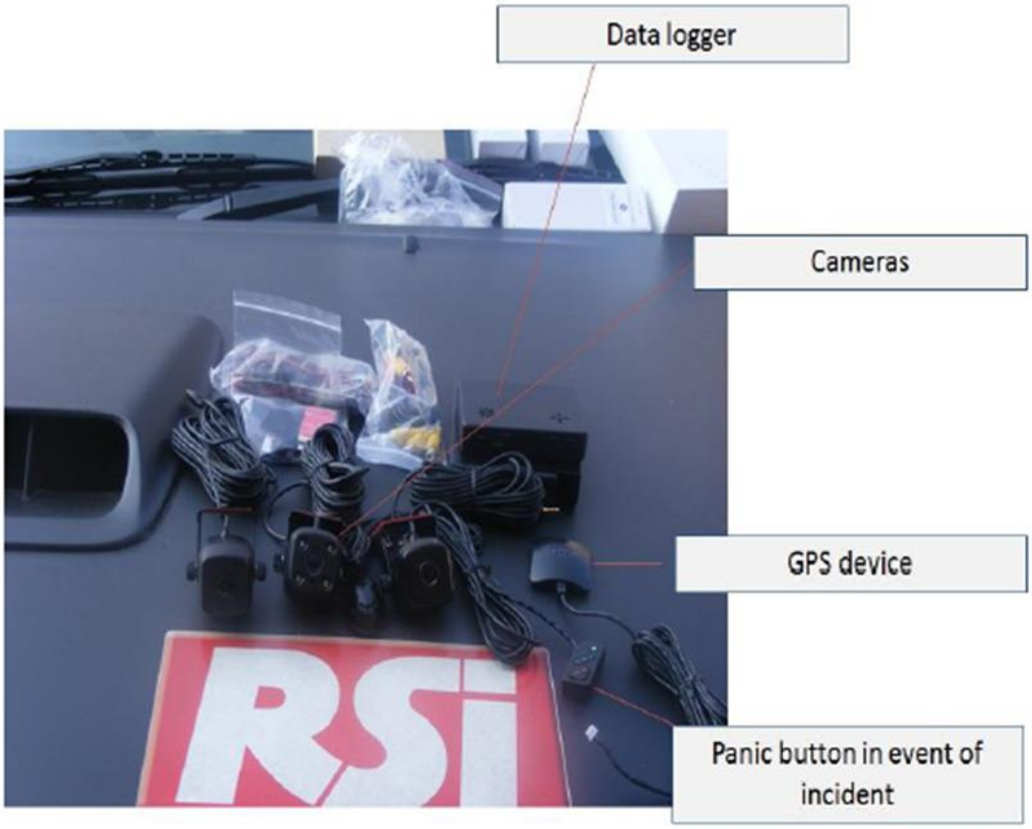
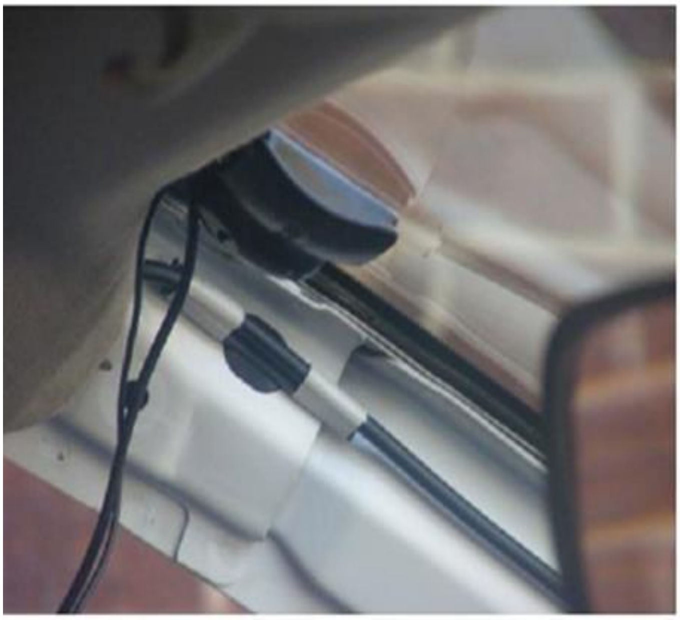


Figure 3-4: Data Acquisition System
Source: Venter (2014)

The equipment was installed in the vehicles of both driver groups by the suppliers of the DAS to ensure correct installation and the devices installed in the vehicle is displayed in Figure 3-5.

GPS Device



Driver-facing camera

Data logger

Rear-facing camera

Figure 3-5: DAS devices installed in vehicle

Source: Venter (2014)

3.3.3 Data collection procedure, storage and duration

The DAS devices started recording data and videos when the power switch was initiated through the activation of the vehicle's ignition. Data was recorded for drivers whenever they were driving and driving videos were recorded both during day and night time conditions, on various roadways, at various intersections and under different weather conditions. Raw databases were prepared for the storage of visual and quantitative data collected from the video recording and the sensors connected to the vehicle. A large amount of data was collected over the study period which resulted in weekly data downloads. Driving data and videos were recorded for each participant over a total period of two months. Data for the two sets of drivers were not collected concurrently. Data was collected for the first set of drivers in March 2013 –April 2013 and for the second set of drivers in June 2013- August 2013. Data was not collected during the same time period because there was only one set of equipment.

3.3.4 Participants

Driver pairs were recruited to participate in the study by means of advertisements placed in local newspapers as well as word of mouth marketing. Participants were given information about the study, informed that data would be collected using their own vehicle and that in return for their participation they would be awarded a GPS. The only criterion for inclusion in the study was that one driver had to be a novice driver and the other driver had to be an experienced driver (preferably a parent/child combination). The reason for this criterion is not specified but it is assumed that it would make the video equipment installation in the vehicle much easier since the driver pairs may be sharing the vehicle. Two pairs of drivers (each a novice and experienced driver) consented to participating and were accepted into the study.

3.3.5 Driving video content

In this study, only the driving videos were used to collect data on driving behaviour and not additional vehicle performance data from the data logger. The researcher only had access to night driving videos and all the night driving videos collected during the study period were analysed and coded for data in the current study. Only these videos were used to collect data on driving behaviour. The video recordings contained information about driving behaviour on various roads, intersections and under different illumination conditions. Data was collected on speed behaviour and violations, gaze behaviour, secondary task engagement and compliance with traffic rules at night time. In some cases when comparisons were drawn between driving behaviour at daytime and at night time (such as speed behaviour or secondary task engagement while driving), the researcher used the driving data produced by Venter (2014) to compare it with driving data produced in the current study.

The night driving videos consisted of three different videos for each driving trip. The **first video** captured material from the driver-facing camera and recorded driver behaviour from the front as indicated in the image from Figure 3-6. This data enabled the observations on driver gaze behaviour, engagement in secondary tasks and compliance with road traffic rules.

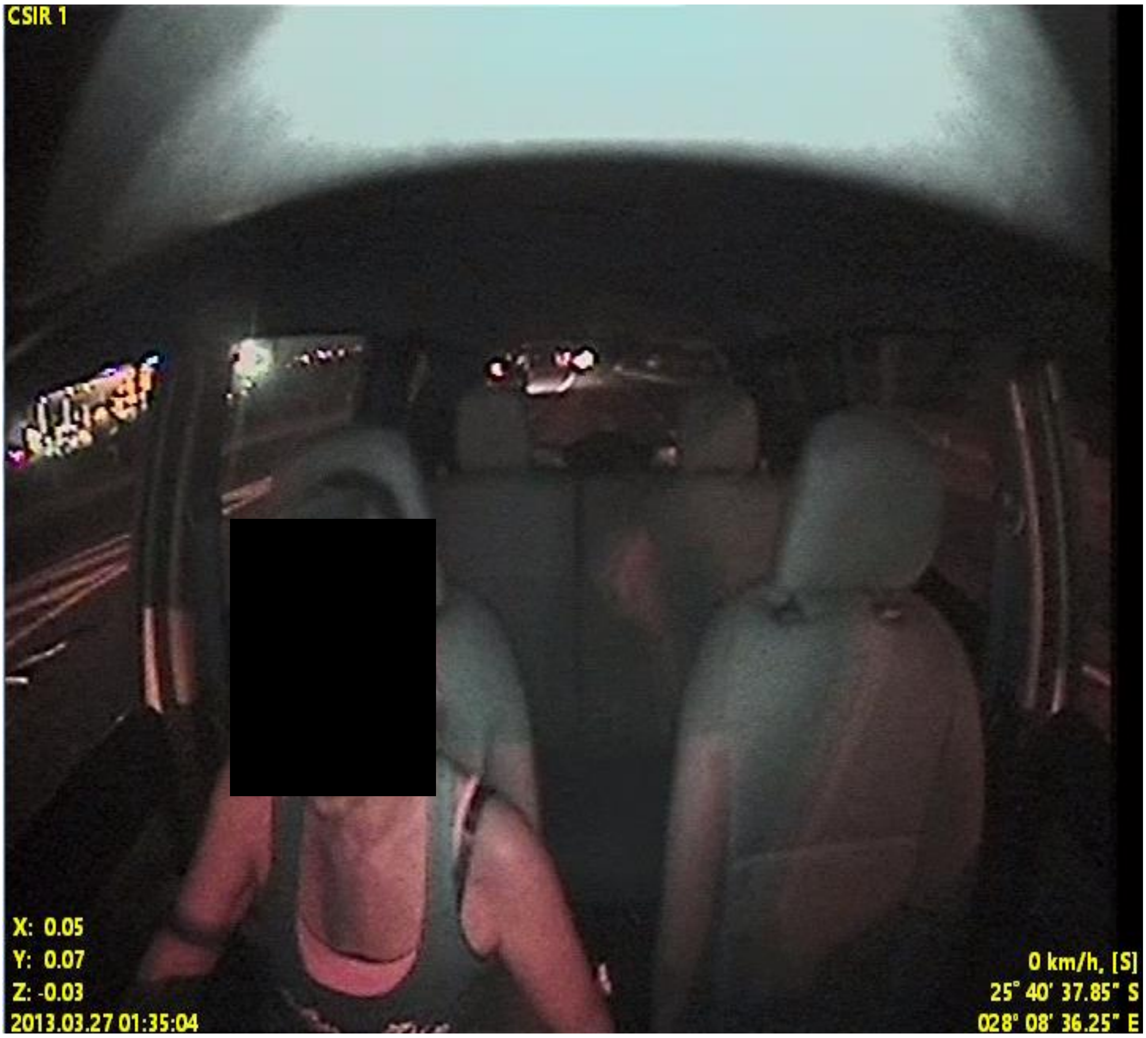


Figure 3-6: Video image from driver-facing camera

The **second video** captured material from the front-facing camera and recorded data on the external road environment in the driver's forward view as indicated in the images from Figure 3-7. This data enabled observations on the road environment, posted speed limits, road types, street lighting conditions and compliance with traffic control devices.

Driving on a road with street lighting

Driving on road with no street lighting

Pedestrians walking on left sidewalk and on right side of the roadway

Waiting at intersection

Figure 3-7: Video images from front-facing camera

The **third video** captured material from the rear-facing camera and recorded data on the external road environment in the drivers' backward view as indicated in the images from Figure 3-8. This data enables observations on the road environment and traffic from the rear view. However, because this data did not yield significant findings on driver behaviour or traffic conditions, it was decided to use video material primarily from the first and second videos.

Driving on an urban road

Driving on a residential road

Figure 3-8: Video images from rear-facing camera

3.3.6 Data extraction and management

Data will be extracted from the night driving videos through visual inspection and manual documentation using Microsoft Excel (see attached Excel spreadsheet). From these videos, data on speed behaviour, gaze behaviour, engaging in secondary tasks and compliance with road traffic rules while driving at night were recorded. Detailed descriptions on the type of data and method of extracting data from the videos for each of these behavioural categories are provided below.

3.3.6.1 Speed behaviour

The researcher did not have access to the data logger but another method of collecting data on speed behaviour was used. Speed data was recorded on both the data logger and the driving videos. In the right hand corner of each video, speed and GPS coordinates were displayed (see Figure 3-9). This information was extracted to record data on driver speed behaviour.

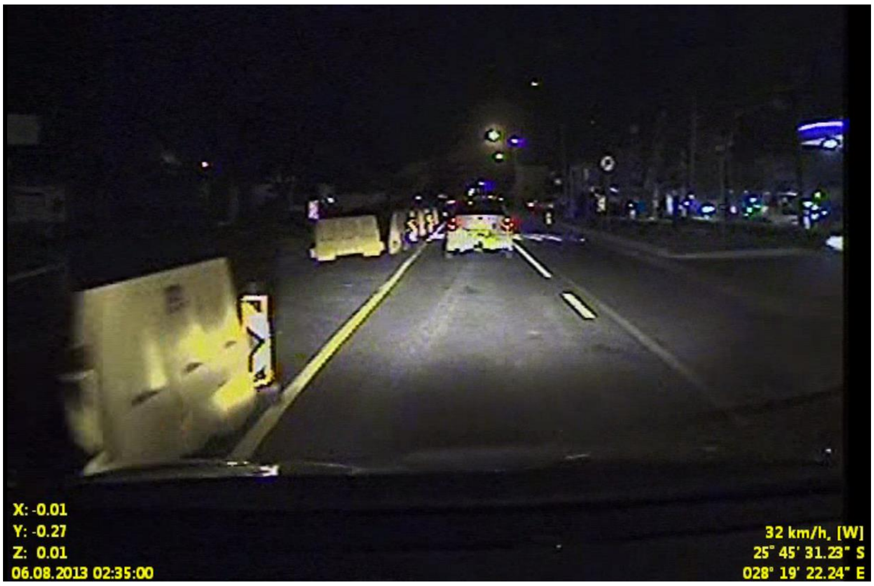


Figure 3-9: Video image displaying driver speed and GPS coordinates

Data was extracted through visual inspection of video material and by manually documenting these speed recordings on a Microsoft Excel spreadsheet. Using a programme/software called 'free video to JPG converter', the video frames for every 5 seconds were extracted from the front-facing video to be analysed. Using this application, the video frames were extracted, downloaded and stored as JPEG images in a folder with a particular ID. More than 5000 JPEG images were downloaded. Each image was manually inspected for driver speed behaviour which was recorded and coded on a Microsoft Excel worksheet. In addition to speed, data on road type, speed limit and illumination type were also recorded. In some instances when the road type or speed limit was not discernible, the GPS coordinates were used to confirm these details using Google Maps. Table 3-1 displays the type of data coded for speed behaviour.

Table 3-1: Description of data coded for speed behaviour for driving videos

Data Variable	Description
Road type and speed limit	• Freeway (120 km/h) • Rural road (100 km/h) • Rural road (80 km/h) • Urban road (60 km/h) • Residential road (60 km/h)
Illumination type	• Street lighting • No street lighting

In this study, a 5 second time interval was chosen to extract video frames as it was regarded as sufficient time to capture changes in speed behaviour and in the driving environment without any significant loss of data between driving events. For this study, video frames as opposed to studying the video in its entirety was selected as the appropriate data material since this facilitates the process of observing and collecting data from the video. Given that drivers are operating at high speed, in rapidly changing environments and that the night driving videos are dark, it is more favourable to extract images that can be studied thoroughly and in-depth. It is important to note that data will be collected from the whole video (i.e. the whole video will be analysed from beginning to end) so no data will be lost. The only distinction is that the video as it has occurred in situ will be broken down in images for every 5 seconds.

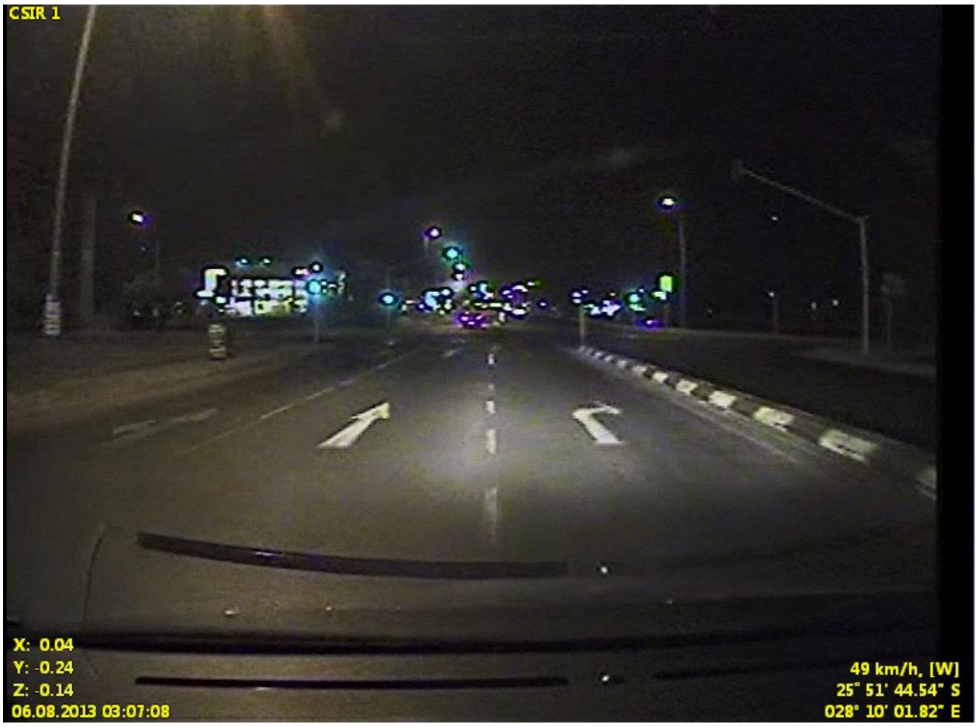
The technique of extracting speed behaviour every 5 seconds from video frames was mainly used to document general speed behaviour on various roads. Collecting speed data when approaching intersections or engaging in secondary tasks was done per second. The video frames also aided in identifying potential intersections for observing gaze behaviour and driver distractions which could be followed up later for closer, per second viewing and inspection.

3.3.6.2 Intersection behaviour

Behaviour at intersections at night was also investigated. This consisted of analysing intersection approach speed and primarily, gaze behaviour at intersections. Data collection on intersection approach speed was initiated 5 seconds before a road sign (such as a stop street or traffic light) or stop line appeared in the video frames for the first time. Speed data on approach to intersections was extracted per second as opposed to every five seconds.

Driver’s visual behaviour at various intersections was also examined. Data collection on gaze behaviour was initiated 5 seconds before a road sign (such as a stop street or traffic light) or stop line appeared in the video frames for the first time. Glance frequency and duration was recorded from the videos at different intersections, when drivers were performing different manoeuvres and under different lighting conditions. Glance frequency refers to the number of times the drivers looked in a particular direction (left, right, left mirror, right mirror, straight ahead, and rear-view mirror). Glance duration refers to the time spent scanning a particular direction. It is recorded from the time the driver directs their gaze/ head in one direction and ends when the driver shifts their gaze/head in another direction. Both the front-facing and driver-facing videos were used to code gaze behaviour at intersections. Figure 3-10 shows video images of drivers approaching various intersections.

Approaching green traffic light



Approaching stop-controlled intersection

Figure 3-10: Video images of driver approaching various intersections

The type of data coded for gaze behaviour at intersections is displayed in Table 3-2.

Table 3-2: Description of data coded for gaze behaviour for driving videos

Data Variable	Description
Intersection type	• Stop-controlled intersection • Traffic light (red) • Traffic light (amber) • Traffic light (green) • T-junction (entering a major road) • T-junction (entering a minor road)
Manoeuvre type	• Straight through • Right turn • Left turn
Gaze direction (proportion and duration)	• Straight • Left • Right • Rear-view mirror • Left side mirror • Right side mirror
Illumination type	• Street lighting • No street lighting
Intersection approach speed	• Driver speed on approach to intersection

The various scan directions recorded for gaze behaviour is shown in Figure 3-11 and a description of these gaze directions are provided in Table 3-3.

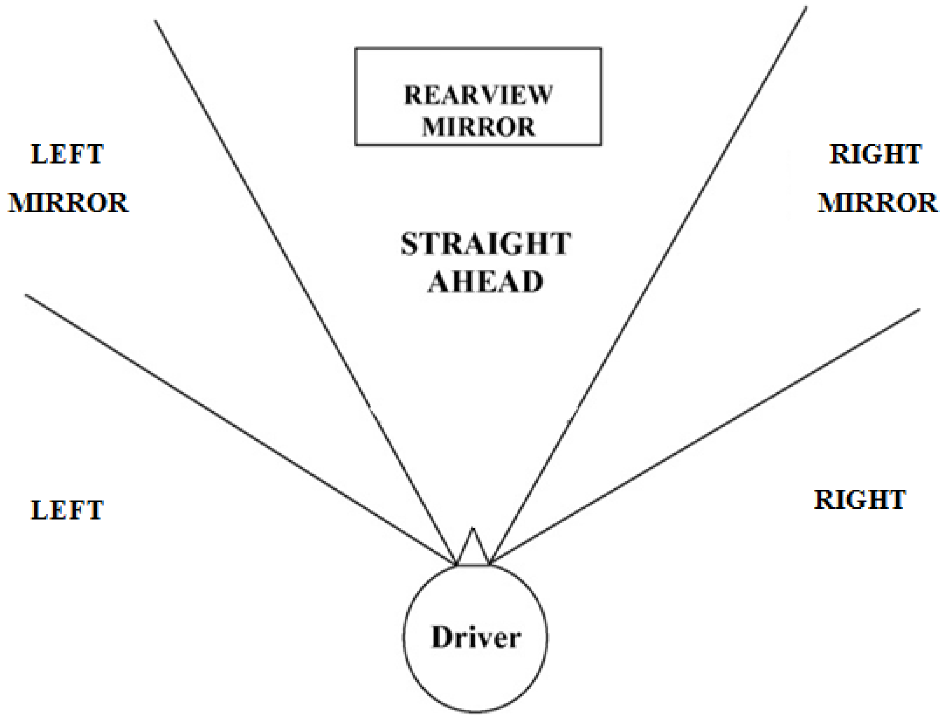


Figure 3-11: Visual scanning areas at intersections

Table 3-3: Description of scan direction

Scan direction	Description
Straight	Eye fixations directed straight to the front of the vehicle
Right	Eye fixations and head movement directed sideways, toward the side of the road
Left	Eye fixations and head movement directed sideways, toward the left of the road
Left side mirror	Eye fixations and head movement directed toward left side mirror
Right side mirror	Eye fixations and head movement directed toward right side mirror
Rear-view mirror	Eye and head movements directed toward rear-view mirror

3.3.6.3 Secondary task engagement

For assessing distractions, the driver-facing videos and the front-facing videos were viewed concurrently. This approach aided in creating a contextual framework in which secondary tasks were executed by providing additional details such as the primary driver action while performing the secondary task, the road or intersection type and speed. Based on the videos, several types of driver distractions were coded. Table 3-4 lists the types of secondary tasks that were differentiated in the video analysis.

Table 3-4: Description of the types of secondary tasks coded for driving videos

Type of secondary task	Description
Mobile phone use	• Relates to all types of phone usage (hand-held and hands-free telephoning, text messaging, checking incoming calls, etc.)
Conversing with passenger	• Passenger is present (can be seen or heard on video) • Driver talks and gestures to passenger
Eating/ drinking	• Driver eats or drinks • Related actions like opening a can or eating from a packet of chips on passenger seat are included
Smoking	• Includes the whole process of smoking • Relates to holding cigarette and lighter in hand, lighting the cigarette, smoking the cigarette and flicking the cigarette out of the window or putting it out
Grooming	• Driver touches or changes something related to his body (e.g. hair, applying make-up, blowing nose) • Short, presumably unconscious actions such as rubbing eyes or touching nose or head are not included

Eyes averted (upward)	• Driver directs eyes away from road and upward • Does not include aversion of eyes upward due to eating, drinking or grooming
Eyes averted (downward)	• Driver directs eyes away from road and downward • Does not include aversion of eyes downward due to sneezing or searching for something
Searching for object	• Driver looks for an object and tries to reach it • Includes looking for objects in vehicle itself or looking for objects in bag or glove compartment, reaching for objects placed in vehicle or arranging things lying around reaching for something
Adjusting vehicle controls	• Not related to driving related inputs to vehicle • Includes adjusting car seat, adjusting heat/air conditioning, opening/closing windows and adjusting radio to change volume; channel or cd.

3.3.6.4 Compliance with road traffic rules

The video frames were also used to examine compliance with traffic rules. Using the video frames, the researcher was able to identify intersections which could then be further inspected to observe compliance with traffic control devices such as stop streets, yield signs and traffic lights. Using the speed data coded for speed behaviour, it was possible to count the frequency of speed violations on various roads and above certain thresholds. Engaging in certain secondary tasks while driving such as mobile phone use is also considered a traffic violation so incidents of these were also counted among the traffic violations observed.

Table 3-5: Description of data coded for compliance with traffic rules

Data Variable	Description
Traffic violation	• Disobeying stop signs • Disobeying yield signs • Failure to yield to pedestrians • Running red lights • Mobile phone use • Seat belt law violation (driver) • Seat belt law violation (passenger) • 1-10 km/h above speed limit • 11-20 km/h above speed limit • 21-30 km/h above speed limit
Road type and speed limit	• Freeways (120 km/h) • Rural road (100 km/h) • Rural road (80 km/h) • Urban road (60 km/h) • Residential road (60 km/h)

3.3.7 Data analysis

All the night driving videos received from the naturalistic driving study were analysed and coded for data. The first week of driving data for all participants were eliminated from the analysis in order to counteract the observer effect that might have been present during the first week of the test drives. The total time of all the videos amounted to 8.4 hours with approximately 2 hours of driving videos coded for each participant. The only criterion for a video to be included in the study was that the driver in the video had to be the participant. In all of the videos received, the participants were the only drivers and thus all the videos were included and coded for analysis.

3.4 Night driving survey

In addition to crash data and naturalistic driving videos, a survey was used to collect information about night driving. Surveys were considered in this study because they are a reliable source of data and allow for ease of comparison and generalisation of results. In addition to this, surveys are a more attractive option than other data collection methods such as interviews, because it is a time-efficient and cost-effective means of measuring the behaviour, attitudes, experiences and opinions of large samples. Surveys provide participants with the opportunity to communicate their own views and experiences which is invaluable data that is not captured by the crash database or naturalistic driving videos. The results from the survey will contribute to providing a comprehensive account of driving at night time as well as elucidate the findings produced by the crash data and driving videos.

A 28-question survey was constructed to collect data on driver's behaviours, attitudes, perceptions and experiences of driving at night. Because no night driving survey currently exists, the items for the questionnaire was derived from the specific themes identified and prioritised for investigation by the researcher. The questionnaire was designed to elicit data on the following specific themes about night time behaviour 1) demographic information and driving history, 2) frequency of aberrant driving behaviour at night, 3) risk perception at day and night time, 4) driver behaviour adjustments at night, and 4) task difficulty while driving at night. Questions were presented in an open- and closed-ended question format to allow participants to express diverging viewpoints or concerns. A determined effort was made to avoid asking leading, ambiguous, long and double-barrelled questions to minimise social desirability. Furthermore, technical, long, excessively general questions and questions that include negatives were also avoided to minimise the risk of erroneous responses. Different and numerous answer choice categories were provided to avoid forcing a particular answer.

Every effort was made to keep the survey short and engaging. After initial development of the questionnaire, a representative sample (in terms of gender, age, driving experience and frequency of driving at night) was assembled to pre-test the questionnaire. Both the electronic and paper forms of the questionnaire were tested. Participants were asked to complete the questionnaire while the researcher observed the total duration of the survey but more importantly, the hesitations and uncertainties that participants displayed when answering questions. In addition to this feedback, suggestions for improvements, deleting, adding and reformulating questions or answer categories were discussed, evaluated and incorporated accordingly. The revised questionnaire was then tested on another representative sample, that was different to the original testing sample, and once this questionnaire was revised according to the feedback, the researcher was confident that the questionnaire was ready to be disseminated. The final version of the questionnaire can be viewed in Appendix A.

Questionnaires were created using Google forms and the electronic survey was the primary version that was distributed. This method was preferable above the questionnaire in paper form because it allowed the results to be captured electronically without the need for entering data into a spreadsheet. However, the paper form of the questionnaire was also available if these were more convenient for the respondent or more than one respondent was completing the questionnaire at a time. The criteria for participation were a valid driver's license and potential respondents needed to be driving at least a few times (2-3 trips) at night per month to be eligible. Questionnaires were distributed to drivers who presented a valid driver's license before commencement of the survey. Potential respondents were approached in parking lots and local traffic departments and asked to complete the questionnaire electronically on a tablet device. Effort was made to have an equal representation of genders (male and female), driver age groups (young, middle-age and elderly) and driver experience groups (novice and experienced drivers). Participation in the survey was completely voluntary and responses were confidential. None of the information obtained from the surveys can be linked to a particular respondent.

Chapter 4: Results

4.1 Introduction

This chapter presents the results obtained from the research. As discussed in the methodology chapter, a number of sources and methods were used to collect data for this study which include crash and fatality data, naturalistic driving videos and surveys. Findings from the crash and fatality data sets are presented first, followed by the results obtained from the driving videos and finally, the results from the night driving survey are presented. A detailed discussion of the results is presented in Chapter 5.

4.2 Analysis of Road Traffic Crashes (RTC) and Road Traffic Fatalities (RTF)

4.2.1 Annual RTC and RTF trends

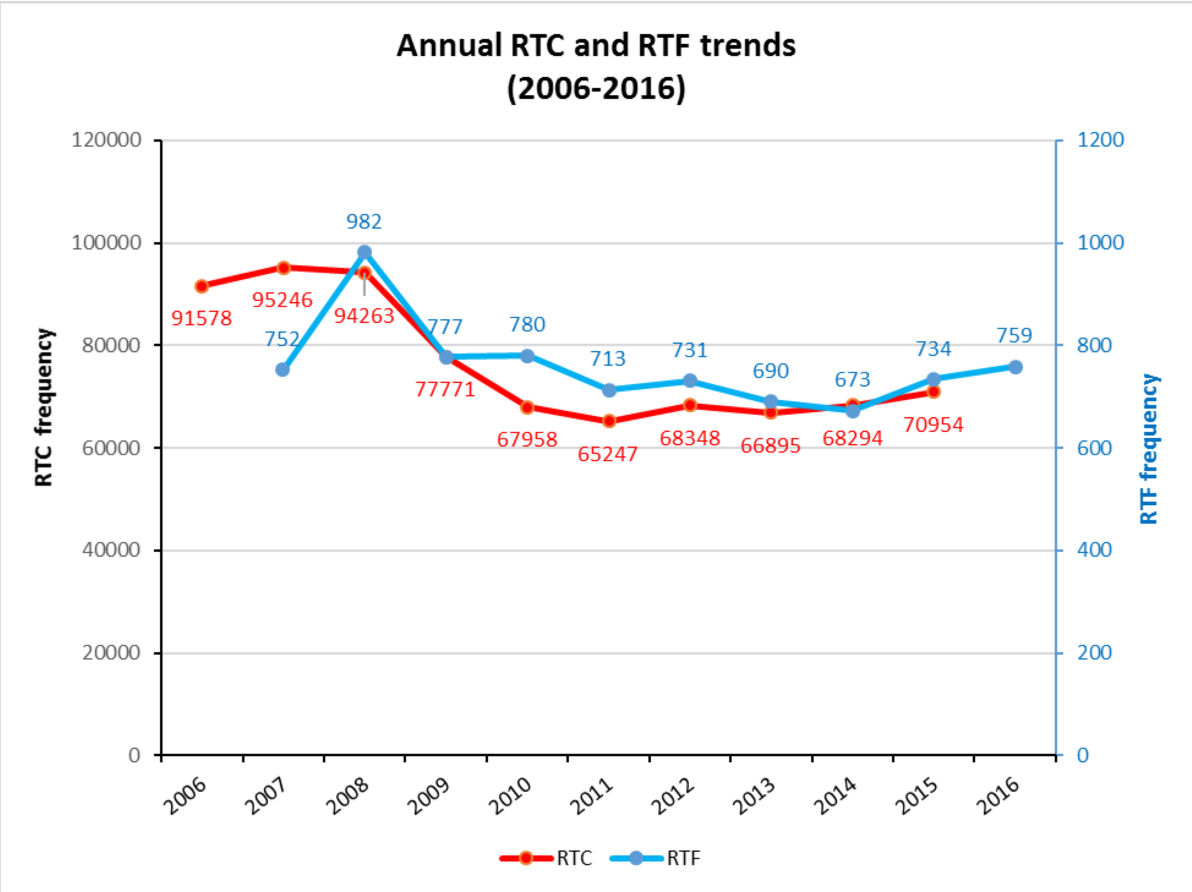


Figure 4-1: Annual RTC and RTF trends from 2006-2016

The annual trends in road traffic crashes and road traffic fatalities for the period 2006-2016 is displayed in Figure 4-1. For road traffic crashes, the dataset comprises of RTCs for the period 2006-2015. Data on RTCs was available for all months of the years included in the period of analysis. RTCs reached its highest frequency in 2007. From 2007-2011, a steady decline in crashes occur until 2012 where the number of crashes slightly increases again. For road traffic fatalities, the dataset consists of fatal injury data for the period of 2007-2016. No data was available for January 2007 which may account for the relatively low fatality frequency observed during this year. RTFS were highest in the year 2008, 2010 and 2009, respectively and the year 2011 reported the lowest number of traffic fatalities. From 2009, there is a general decrease in the number of fatalities until 2014-2016 where fatalities are on the rise again.

4.2.2 Monthly RTC and RTF trends

1. **Road traffic crashes (RTC)**

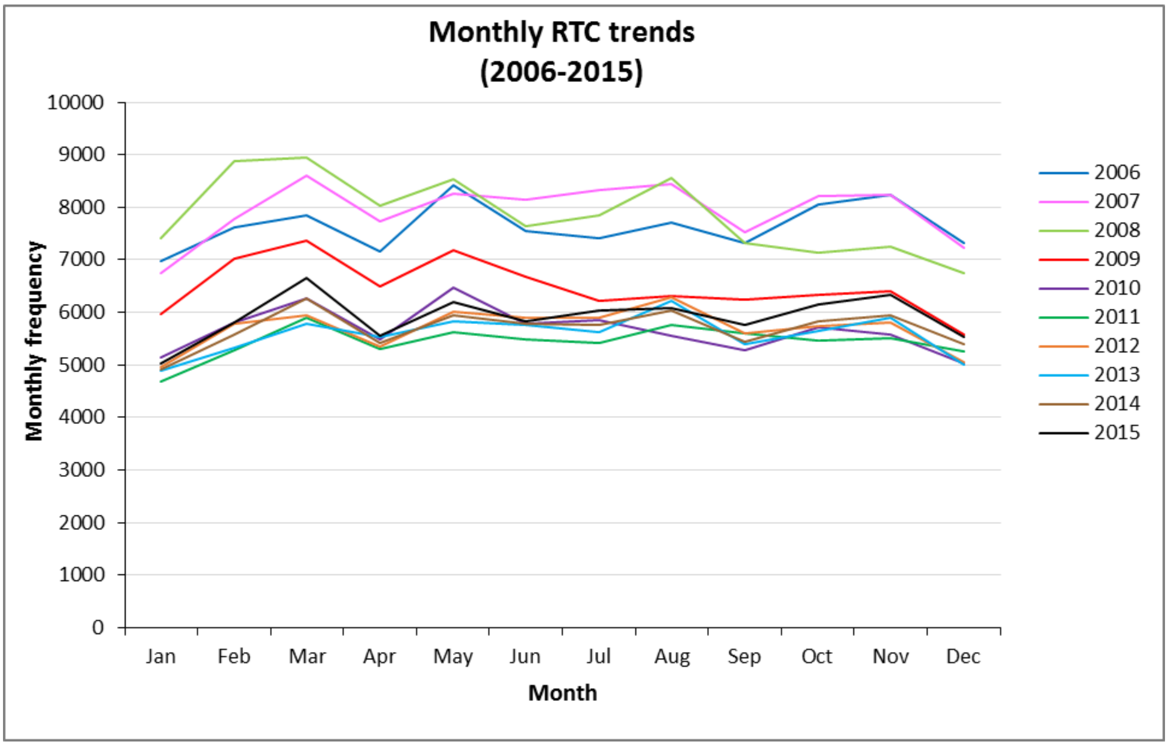


Figure 4-2: Monthly RTC trends from 2006-2015

The distribution of road traffic crashes by month is shown in Figure 4-2. Monthly frequencies are the total number of crashes observed in each month of a year. On average, road traffic crashes peak during the months of March, May, August and November. The trend in monthly crash frequencies is homogenous for most of the years observed in the study period.

2. Road traffic fatalities (RTF)

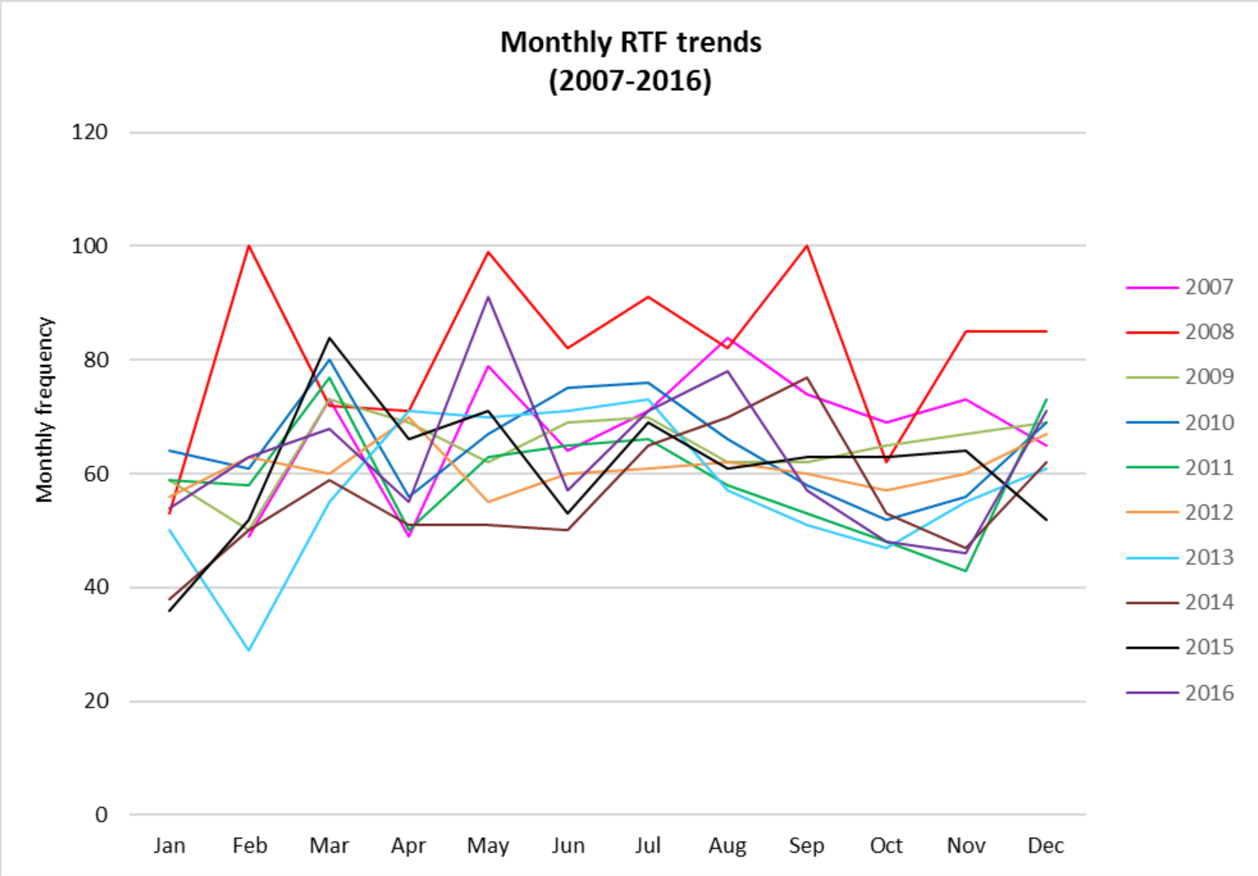


Figure 4-3: Monthly RTF trends from 2007-2016

The distribution of road traffic fatalities by month is shown in Figure 4-3. On average, road traffic fatalities are highest during the months of March, May, July, August and November. The monthly traffic fatality frequencies observed for RTFs is similar to the trend observed for RTCs. However, the trend in monthly fatality frequencies is less homogenous for most of the years observed in the study period.

4.2.3 Daily RTC and RTF trends

The distribution of road traffic crashes and fatalities by day of week is shown below. For the analysis of RTCs and RTFs, a week comprises Monday, Tuesday, Wednesday, Thursday and Friday while a weekend comprises Saturday and Sunday.

1. **Road traffic crashes (RTC)**

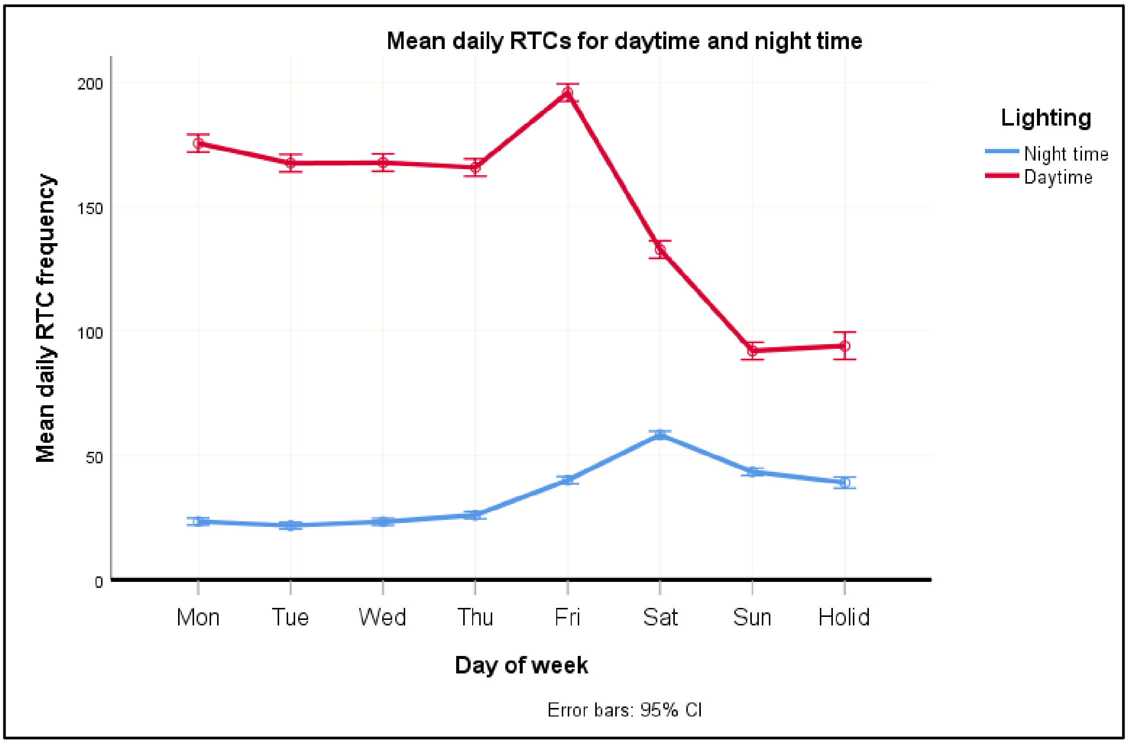


Figure 4-4: Mean daily RTCs for daytime, night time and public holidays

The distribution of RTCs by day of week is shown in Figure 4-4. Mean daily RTCs are higher during daytime compared to night time. For daytime periods, RTCs are uniformly higher during weekdays. RTCs reach a peak on Friday (mean=196) and thereafter, crashes generally decrease on the weekend and public holidays. During daylight hours, RTCs occur more frequently during the weekday.

For night time periods, a contrary trend is observed. RTCs are uniformly lower during weekdays and gradually increases from Thursday until it peaks on Saturday (mean= 58). Thereafter, crashes on Sunday (mean= 43) and public holidays (mean= 39) are lower but remain relatively high compared to fatalities during the week. During hours of darkness, RTCs occur more frequently during the weekend.

2. Road traffic fatalities (RTF)

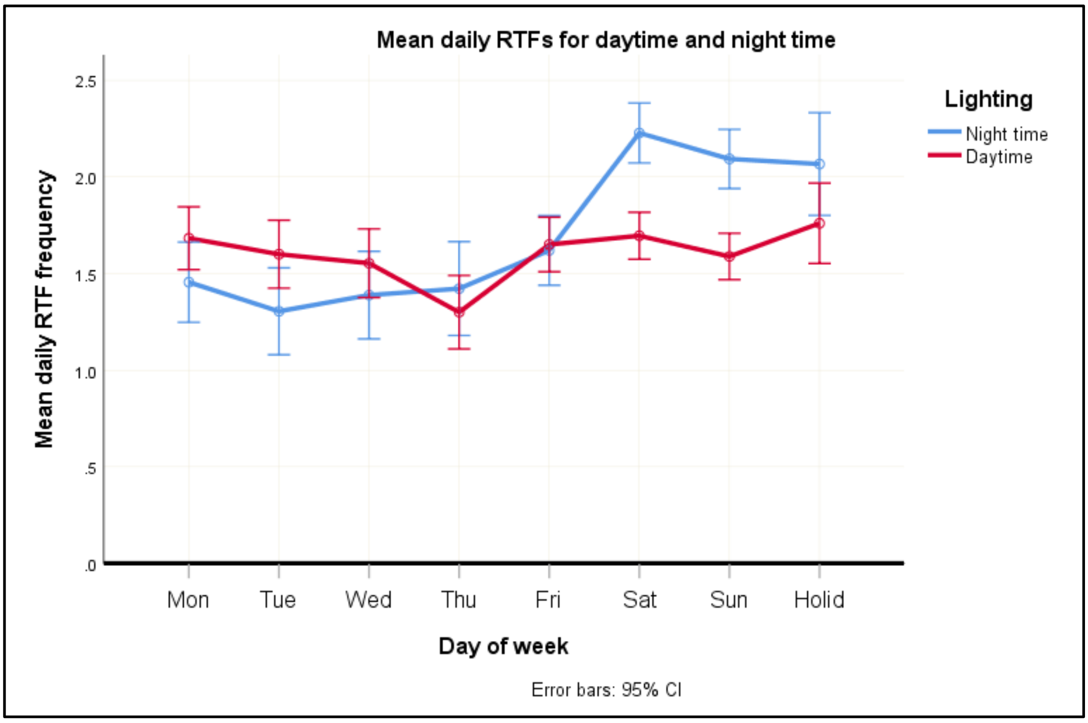


Figure 4-5: Mean daily RTFs for daytime, night time and public holidays

The distribution of RTFs by day of week is shown in Figure 4-5. For daytime periods, the frequency of RTFs is almost uniform during the week and weekend. Slight variations occur on Thursday (mean= 1.30) where RTFs reaches its lowest point and on Sunday (mean= 1.6). The frequency of RTFs on Saturday is slightly higher than the frequency of RTFs on any weekday, except for Monday where the frequency of RTFs is similar. RTFs on public holidays are also slightly higher than RTFs on Saturday. During daylight hours, the frequency of fatalities occurring during the week and weekend are similar, with most RTFs occurring on Saturday, Monday, and public holidays.

For night time periods, RTFs are uniformly lower during the week and steadily increase from Thursday until it peaks on Saturday (mean= 2.2). Thereafter, RTFs on Sunday and public holidays decrease but remain relatively high compared to RTFs during the week. RTFs on Friday and Thursday are relatively higher during the week and the frequency of RTFs on Sunday and public holidays are comparable. During hours of darkness, most fatalities occur during the weekend, most notably on Saturday and Sunday.

4.2.4 Hourly RTC and RTF trends

The distribution of crashes and fatalities according to daytime, night time and twilight periods are displayed in Figure 4-6 and Figure 4-7. In this analysis section of RTC and RTF trends according to time of day, RTC and RTF crash frequencies for the daytime period was taken as it appears in Figure 4-6 and Figure 4-7. Conversely, RTC and RTF crash frequencies analysed for the night time period included crash and fatality frequencies at night time, evening astronomical twilight and morning astronomical twilight. It was decided to combine crash frequencies for night time with crash frequencies for evening and morning astronomical twilight periods, as these twilight periods are characteristically dark and comparable to night time conditions. The combination of crash frequencies during night time and astronomical twilight periods were only done in this section to report on RTC and RTFs trends at night time.

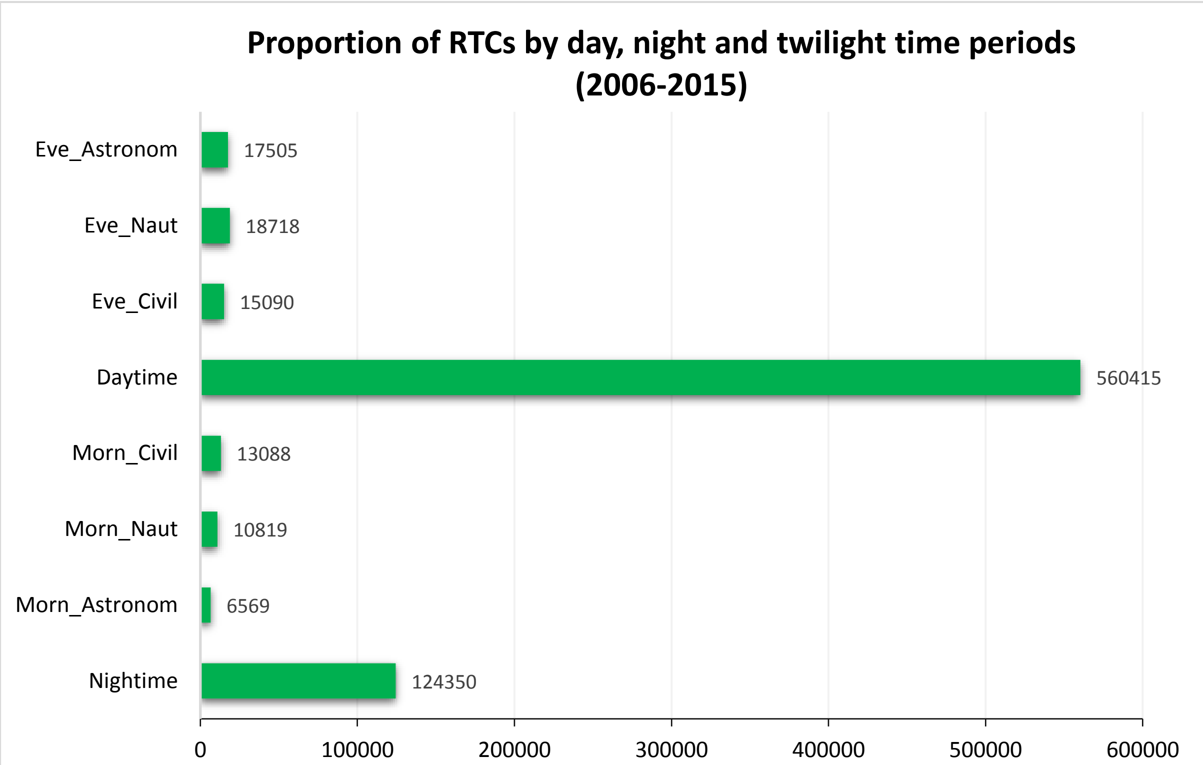


Figure 4-6: Distribution of RTCs by day, night and twilight time periods

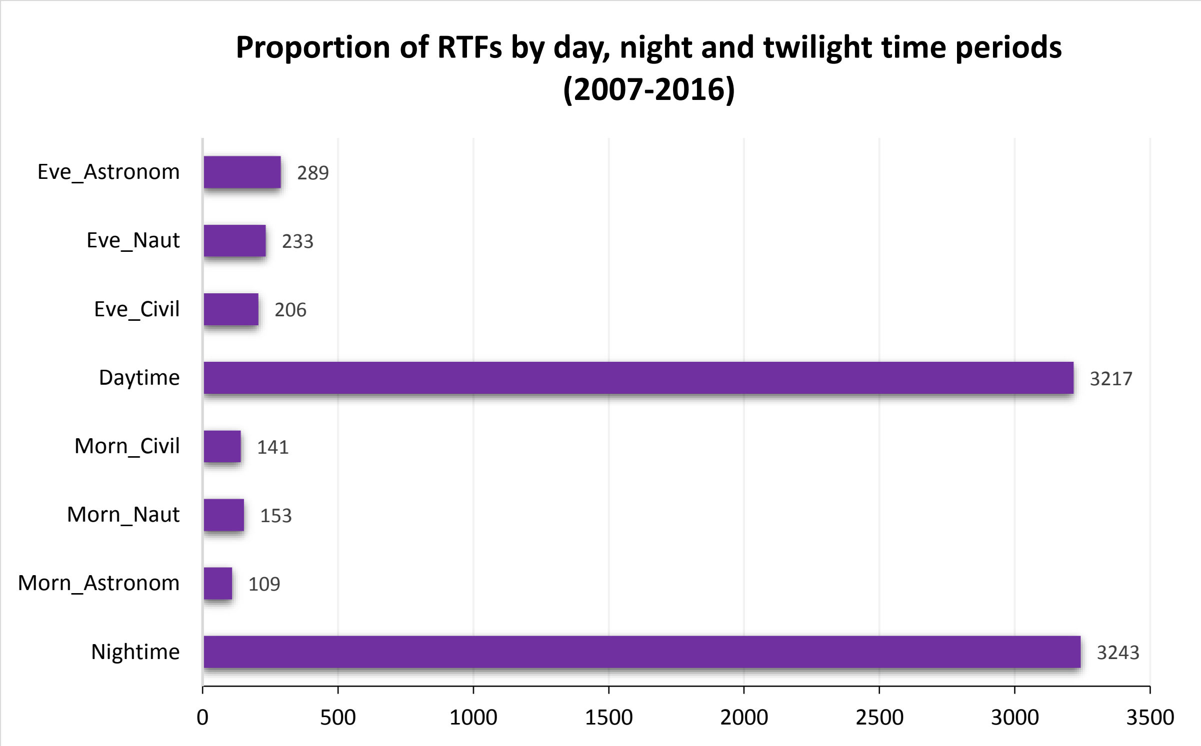


Figure 4-7: Distribution of RTFs by day, night and twilight time periods

A significant number of crashes occurred during the daytime period (73%, n= 560415) while a relatively smaller number of crashes occurred during the night time period (20%, n= 148424). A slightly higher number of fatalities occur during night time (48%, n= 3641) compared to day time (42%, n= 3217). The number of RTCs decreases from daylight to darkness by a large margin. Conversely, a slight increase occurs in the number of RTFs from daylight to darkness. The difference in crashes recorded for daytime and night time is considerable while the difference in fatalities recorded for daytime and night time are marginal. The data also demonstrates a proportional relationship between RTCs and RTFs during daytime conditions and RTCs and RTFs during night time conditions. For the daytime period, the proportion of crashes (73%, n= 560415) is almost twice the number of fatalities (42%, n=3217). For the night time period, the proportion of crashes (20%, n= 148424) is more than twice the number of fatalities (48%, n= 3641).

1. **Road traffic crashes (RTCs)**

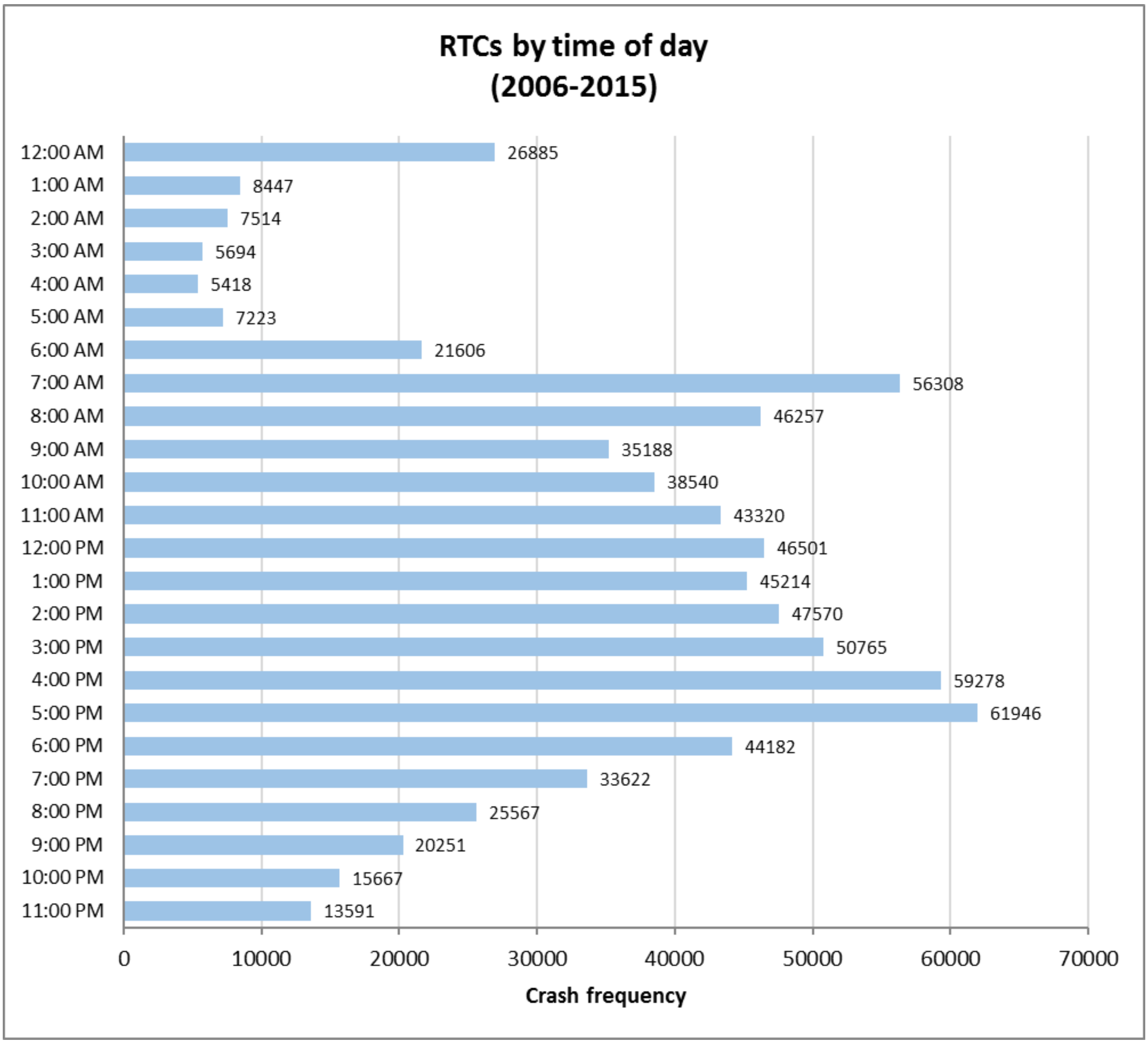


Figure 4-8: Hourly RTC trends

The breakdown of road traffic crashes per hour is displayed in Figure 4-8. Most traffic crashes occurred at 05:00 PM (8.1%), 04:00 PM (8%) and 07:00 AM (7%), respectively. Relative to crash frequency in the late morning and early afternoon period, a large number of crashes also occurred in the mid-afternoon period at 03:00 PM and 02:00 PM respectively. The proportion of crashes during 03:00 PM and 02:00 PM are even higher than the number of crashes occurring during the earlier part of the morning peak period (06:00 AM). During night time, the number of crashes sharply declines with advancing night hours. This trend continues until 12:00 AM when a steep rise in crashes (3.5%) occurs. The increase in the frequency of crashes during 12:00 AM is almost double the number of crashes in the preceding hour (1.8% at 11:00 PM) and triple the number of crashes in the following hour (1.1% at 01:00 AM).

2. Road traffic fatalities (RTFs)

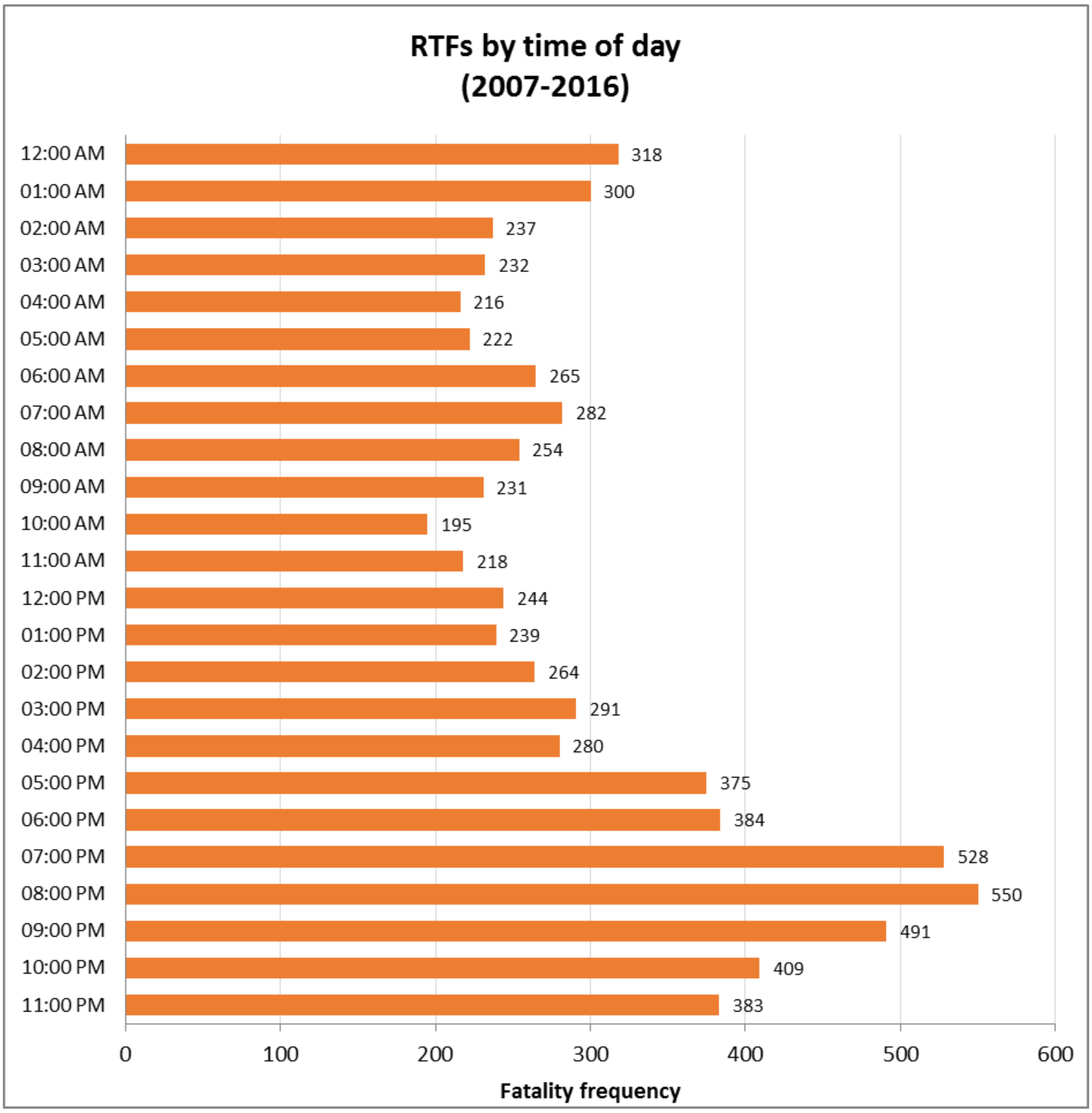


Figure 4-9: Hourly RTF trends

The distribution of road traffic fatalities per hour is displayed in Figure 4-9. Most traffic fatalities occurred at 8 PM (7.4%), 7 PM (7.1%) and 9 PM (7%), respectively. The number of fatalities increases as night time hours approach. Similar to road traffic crashes at night, a downward trend in the number of traffic fatalities at night is apparent. However, this decline occurs gradually and much later in the night from 9 PM onwards. The earlier time slot (7 PM-8 PM) of the night time period are characterised by a higher number of fatalities. The smallest number of fatal crashes occurred at 4 AM with only 2.9% of fatalities occurring during this time slot. Interestingly, the number of fatalities occurring from 01:00 AM – 05:00 AM (n= 1207) is almost comparable to the number of fatalities that occur from 01:00 PM – 05:00 PM (n= 1449). This is unexpected since the two traffic conditions are vastly different.

Traffic fatalities were also shown to be higher at night time compared to daytime when analysing the ratio of RTCs to RTFs. According to the results displayed in Table 4-1, the percentages of RTFs greater than 1% occurs predominantly during night-times periods between 7:00 PM and 6:00 AM. This indicates that at night time there is a higher frequency of RTFs than RTCs.

Table 4-1: Ratio of RTCs to RTFs by time of day

Time of incident	RTC	RTF	% Fatalities
12:00 AM	26885	318	1.183
1:00 AM	8447	300	3.552
2:00 AM	7514	237	3.154
3:00 AM	5694	232	4.074
4:00 AM	5418	216	3.987
5:00 AM	7223	222	3.074
6:00 AM	21606	265	1.227
7:00 AM	56308	282	0.501
8:00 AM	46257	254	0.549
9:00 AM	35188	231	0.656
10:00 AM	38540	195	0.506
11:00 AM	43320	218	0.503
12:00 PM	46501	244	0.525
1:00 PM	45214	239	0.529
2:00 PM	47570	264	0.555
3:00 PM	50765	291	0.573
4:00 PM	59278	280	0.472
5:00 PM	61946	375	0.605
6:00 PM	44182	384	0.869
7:00 PM	33622	528	1.570
8:00 PM	25567	550	2.151
9:00 PM	20251	491	2.425
10:00 PM	15667	409	2.611
11:00 PM	13591	383	2.818

4.2.5 RTCs and RTFs according to illumination condition

i. Road traffic crashes (RTC)

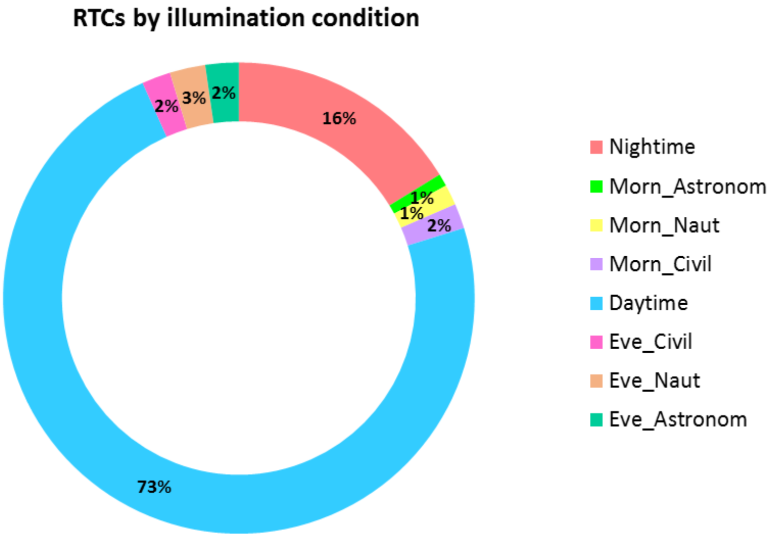


Figure 4-10: RTCs by illumination condition

The distribution of road traffic crashes according to illumination condition is displayed in Figure 4-10. Road traffic crashes occurring during the twilight periods account for 11% of all crashes. It is also important to note that a higher number of crashes occur during the evening twilight period (7%, n= 51313) compared to the morning twilight period (4%, n= 30476). The highest number of traffic crashes was observed during the evening nautical period.

Road traffic crashes were also analysed by time of day and illumination condition to establish whether crash rates during evening twilight and morning twilight are owing to traffic volumes exclusively, or is an effect of ambient illumination as well. Analysing crashes that occur during twilight periods but that fall outside of peak traffic periods (06:00 AM – 08:00 AM for the morning peak traffic period and 04:00 PM – 06:00 Pm for the evening peak traffic period) can isolate the 'twilight effect' and enable an examination of the effect of changing visibility conditions on road traffic crashes. The results are shown in Figure 4-11.

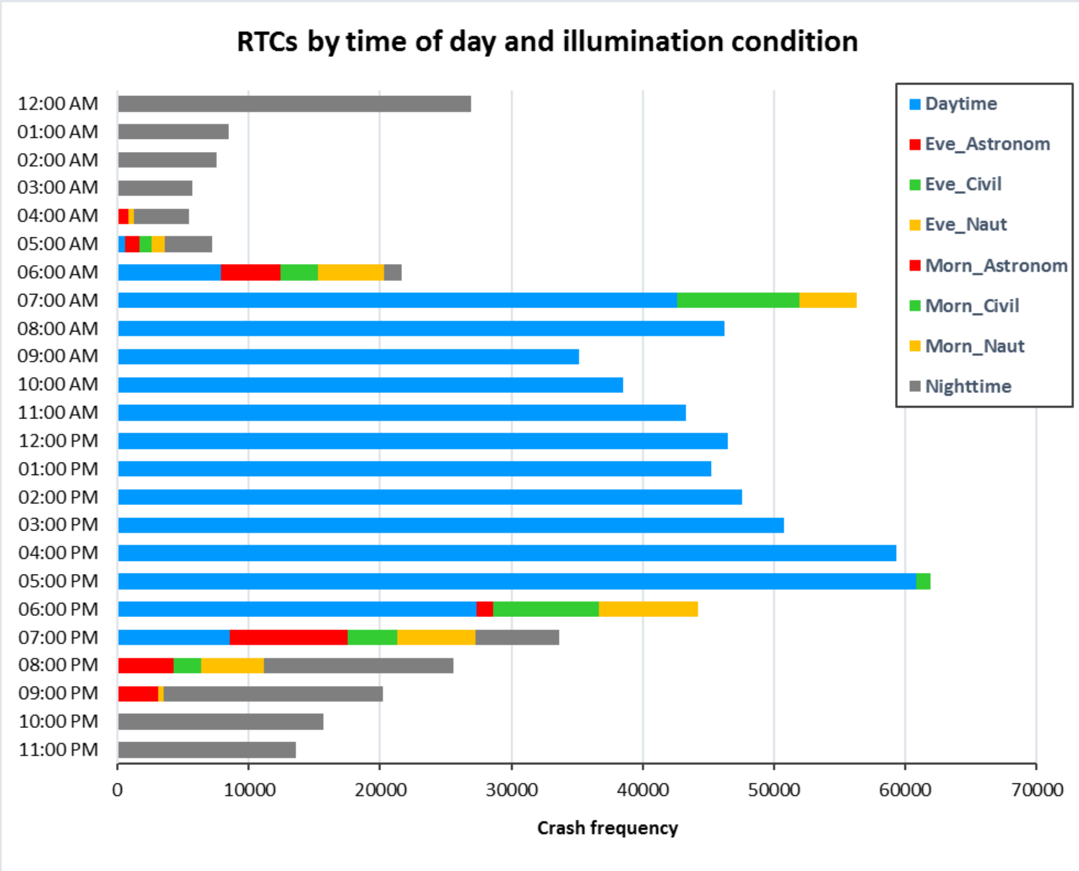


Figure 4-11: RTCs by time of day and illumination condition

According to the graph, during 4:00 Am and 5:00 AM (morning twilight) a smaller proportion of crashes during the twilight period are evident. However, when considering the number of crashes occurring from 6:00 PM- 8:00PM (evening twilight period) a higher proportion of traffic crashes occur. These crashes occur during twilight periods and hours that are characterised by lower traffic volumes which mean that these crashes are owing to visibility conditions and not primarily, traffic conditions.

ii. Road traffic fatalities (RTF)

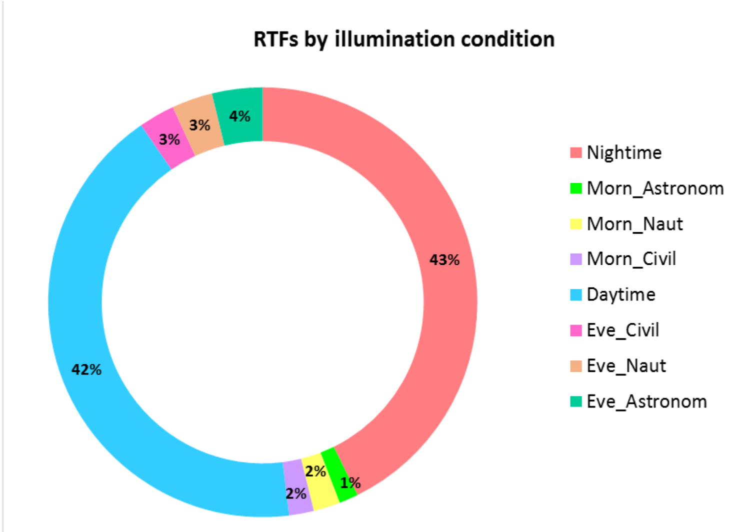


Figure 4-12: RTFs by illumination condition

The breakdown of road traffic fatalities according to illumination condition is displayed in Figure 4-12. Road traffic fatalities occurring during the twilight periods account for 15% of all fatalities which is slightly higher than the frequency of crashes occurring during the twilight periods. Similar to trends observed for traffic crashes, fatalities occurring during the evening twilight (10%, n= 728) are twice as high as the fatalities occurring during the morning twilight (5%, n= 403). Compared to traffic crashes, the frequency of fatalities during each twilight period rises (except for morning nautical twilight and evening astronomical twilight). This indicates that the traffic fatality frequency is higher during twilight periods when compared to crash risk.

As with traffic crashes, road traffic fatalities were also analysed by time of day and illumination condition to establish whether crash rates during evening twilight and morning twilight are owing to traffic volumes exclusively, or is an effect of ambient illumination as well. The results are shown in Figure 4-13.

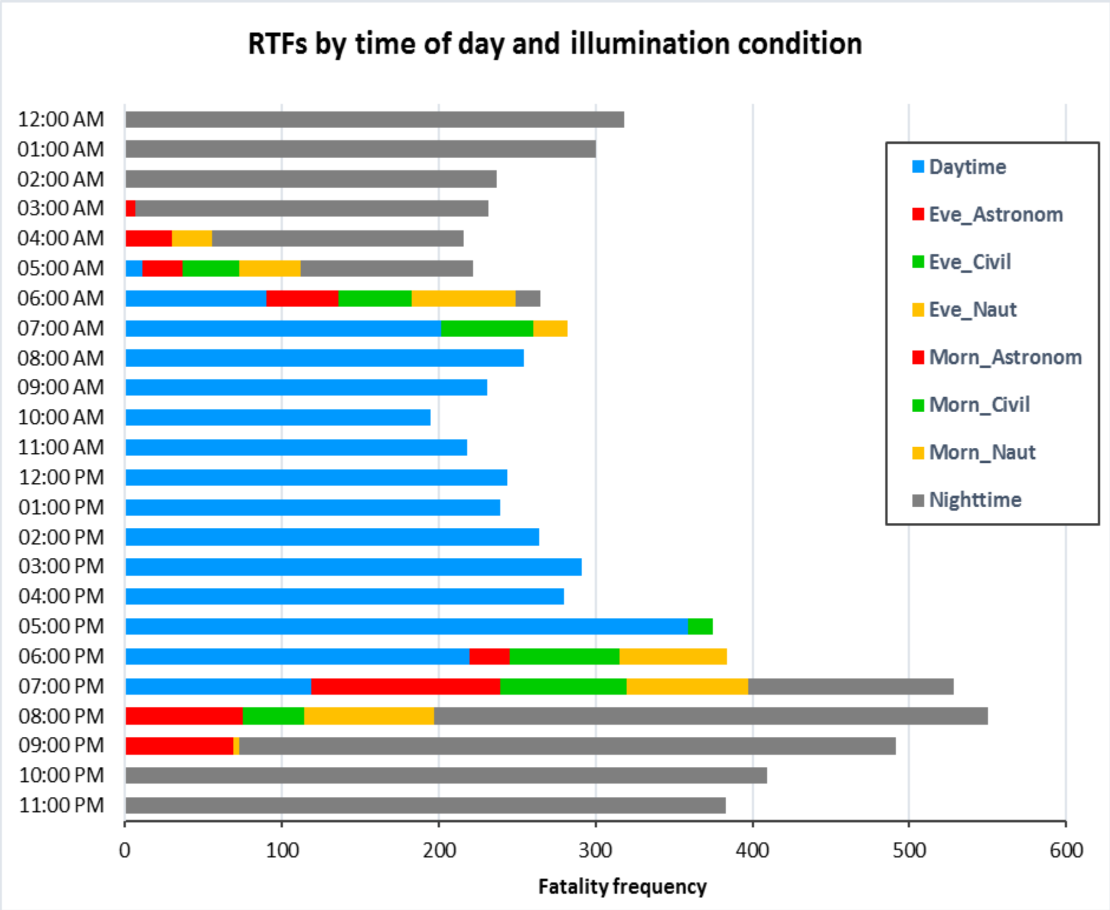


Figure 4-13: RTFs by time of day and illumination condition

Similar to the trends observed for traffic crashes, a smaller proportion of crashes occur at 04:00 AM and 05:00 AM (morning twilight) and a higher proportion of traffic crashes occur at 06:00 PM and 08:00PM (evening twilight). Given that these traffic fatalities occur during twilight periods and outside of peak traffic periods (06:00 AM – 08:00 AM for the morning peak traffic period and 04:00 PM – 06:00 Pm for the evening peak traffic period), these fatalities can also primarily be attributed to visibility conditions and not traffic conditions.

4.2.6 RTCs according to crash type

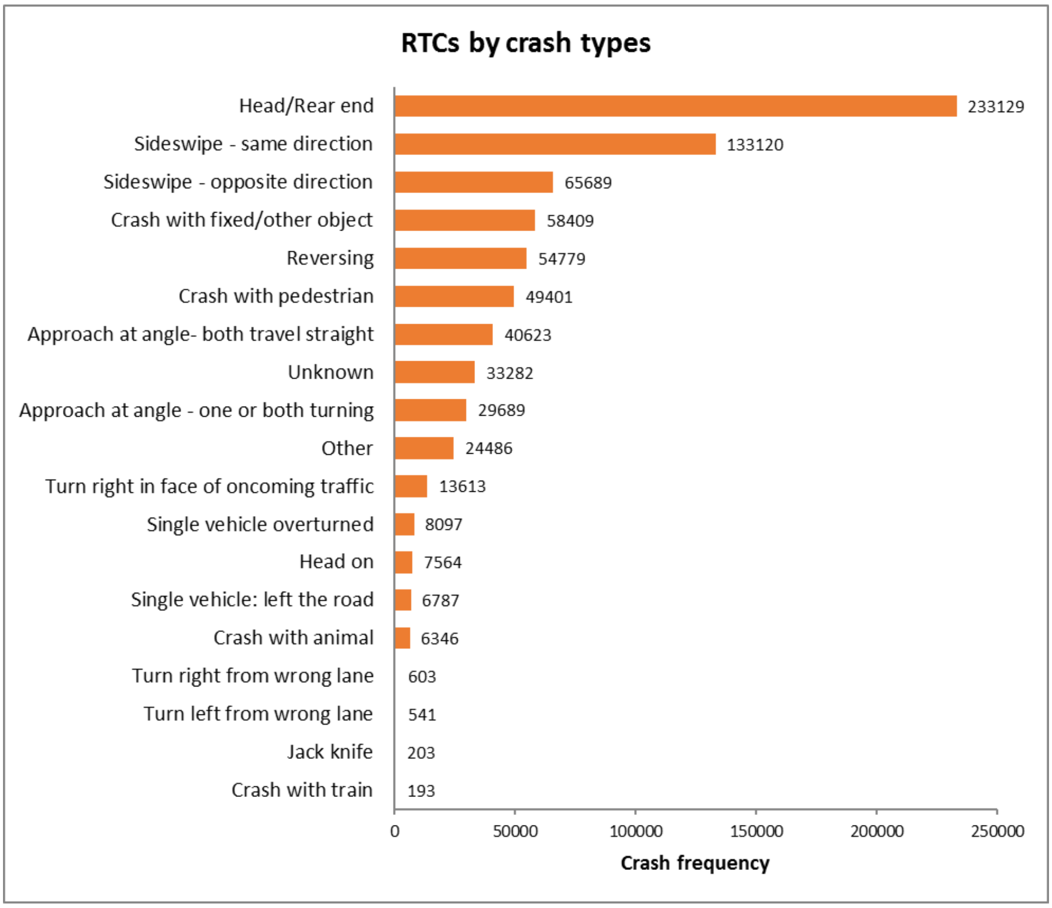


Figure 4-14: RTCs by crash type

Figure 4-14 displays the distribution of crashes according to crash type. Four crash types were combined into one category called "turning". This crash type includes crashes recorded as approach at angle - one or both turning, turn right in face of oncoming traffic, turn left from wrong lane and turn right from wrong lane. The single vehicle crash type is a combination of single vehicle overturned and single vehicle left the road.

The most common crashes are head/rear end (30.4%), sideswipe (same direction) (17.4%) and sideswipe (opposite direction) (9%). Figure 4-15 displays the distribution of crashes according to illumination type which enables an analysis of crashes occurring at night. At night time, crashes vary according to the period of the night. From 6:00 PM-1:00 AM, the dominant crash type is head/rear end crashes followed by sideswipe crashes (same direction). Head-on crashes continuously decline with advancing night time hours but peaks at midnight (a twofold increase is apparent at this time). From midnight to 5:00 AM, the frequency of crashes with fixed/other objects increases and predominates. Crashes with fixed objects remain relatively stable throughout the day and night time but remains the predominant crash type in the early morning hours.

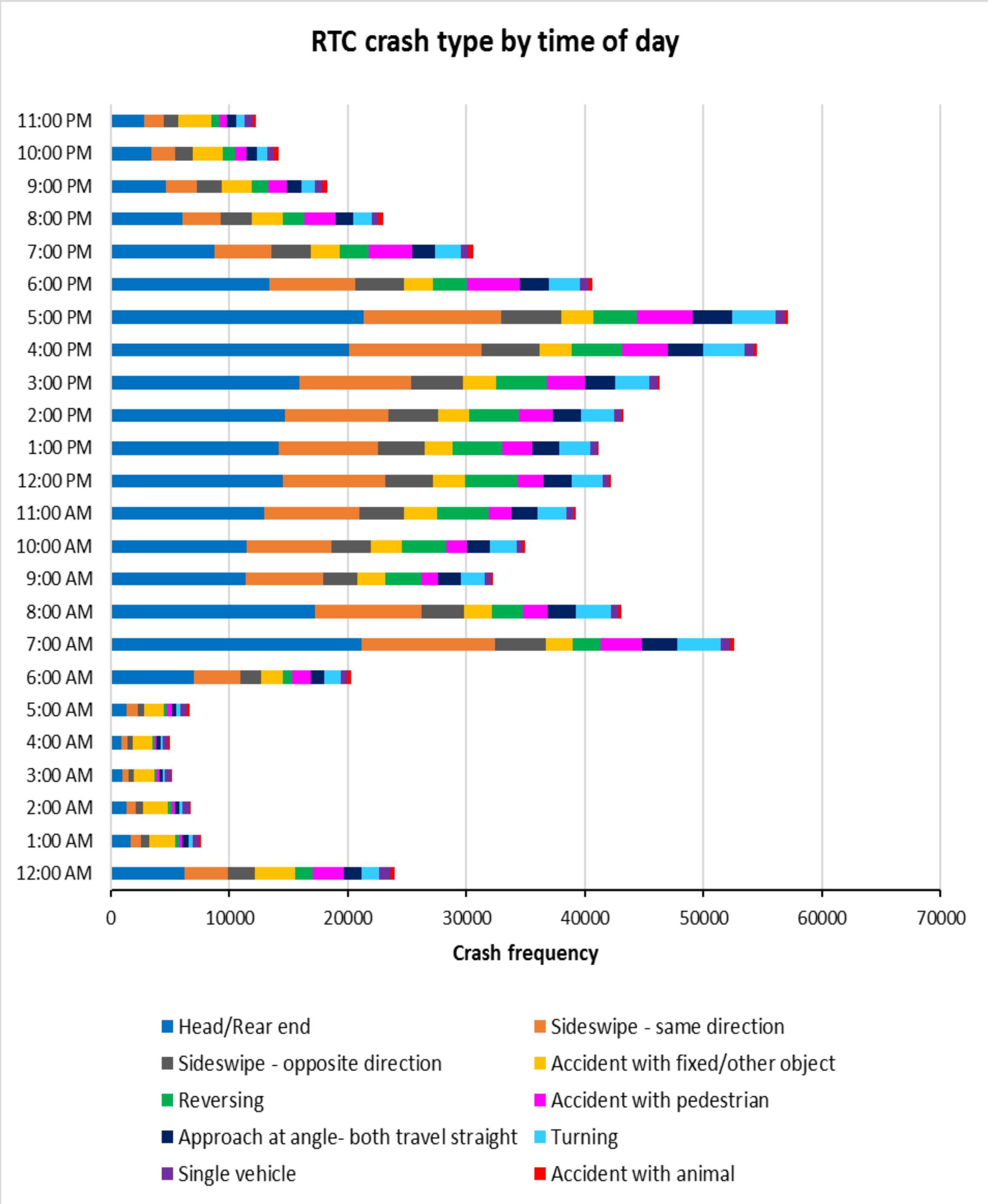


Figure 4-15: RTC crash type by time of day

4.2.7 RTFs according to age and gender

RTFs were analysed according to age and gender to facilitate the identification of road users at risk at night time. This section provides an overview of RTFs according to age and gender broadly. In the next sections, RTFs are analysed according to the gender, age and race of the road user (i.e. driver and pedestrians) to provide greater detail on the characteristics of road users that experience greater risk at night time.

The distribution of fatal injuries by age, gender and illumination condition is shown in Figure 4-16. A total number of 204 fatalities (2.69 percent) were recorded with age 0 and no age record (blank cells) was found for 79 fatalities. One fatality was recorded with the age of 120 years old. Age records with 0 were excluded from the analyses as these seem to be unreasonable. When the age of the victim is not known, it is often recorded as zero age by the police or other data capturers. Fatalities with missing age records and one record with 120 years of age were also excluded from the analysis of fatal injuries by age.

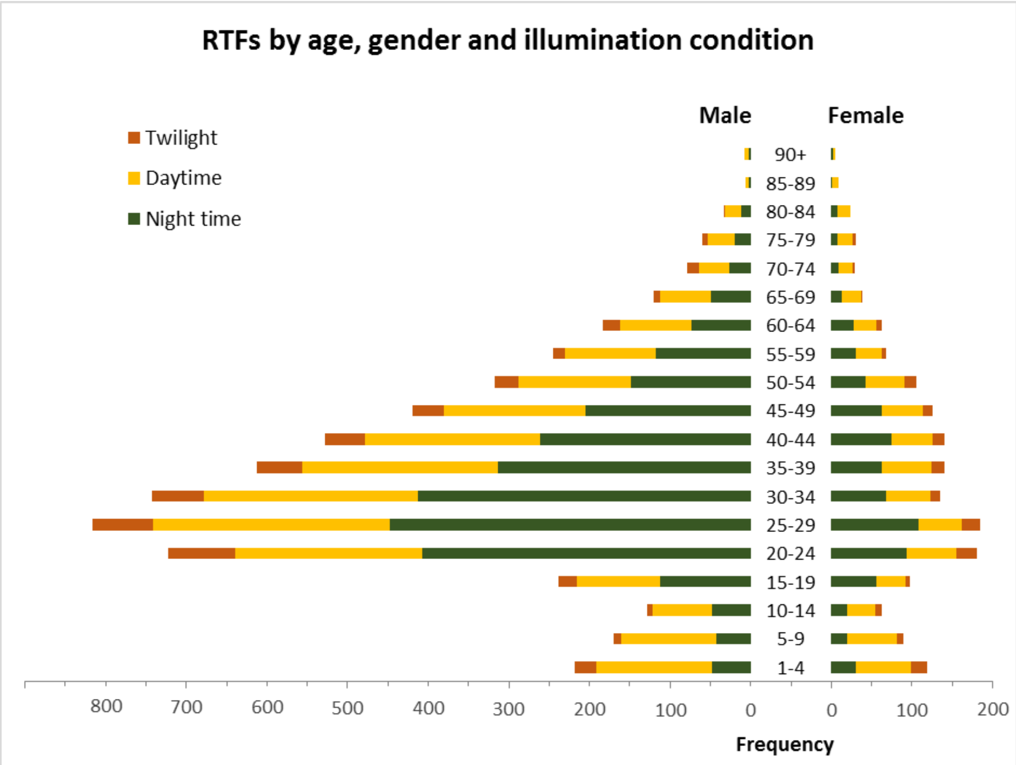


Figure 4-16: RTFs by age, gender and illumination condition

In terms of gender, road traffic fatalities are higher during night time for both male and females. The frequency of fatalities for males during day and night time are 42% and 58% respectively, and the frequency of fatalities for females is 44% and 56% respectively. This indicates that both gender groups have an almost equal risk of fatal crashes at day and night time. However, in terms of overall traffic fatality frequencies, traffic fatalities for males were substantially and consistently higher than traffic fatalities for females for both day and night time conditions.

The ratio of male to female RTFs by time of day is shown in Table 4-2.

Table 4-2: RTF ratios of male to female road users by time of day

Time of Injury	Male	Female	Unknown	Total	Ratio M:F
6:00 AM	210	55		265	3.82
7:00 AM	218	64		282	3.41
8:00 AM	190	64		254	2.97
9:00 AM	179	52		231	3.44
10:00 AM	146	48	1	195	3.04
11:00 AM	173	45		218	3.84
12:00 PM	188	56		244	3.36
1:00 PM	184	55		239	3.35
2:00 PM	198	66		264	3.00
3:00 PM	218	73		291	2.99
4:00 PM	210	69	1	280	3.04
5:00 PM	290	83	2	375	3.49
6:00 PM	284	100		384	2.84
7:00 PM	402	125	1	528	3.22
8:00 PM	427	122	1	550	3.50
9:00 PM	388	103		491	3.77
10:00 PM	336	73		409	4.60
11:00 PM	301	82		383	3.67
12:00 AM	254	64		318	3.97
1:00 AM	237	63		300	3.76
2:00 AM	188	49		237	3.84
3:00 AM	180	52		232	3.46
4:00 AM	167	49		216	3.41
5:00 AM	172	50		222	3.44

During daylight hours, male's involvement in traffic fatalities is generally three times higher than females (except for 08:00 AM and 03:00 PM), with the highest male-to-female fatality ratio occurring from 9:00 AM- 2:00 PM and at 11:00 AM. However, during night time hours, male fatalities increase substantially compared to females and their involvement in traffic fatalities is almost four time times higher than females with the male-to-female ratios more pronounced from 8:00 PM to 6:00 AM.

In terms of age, fatal crash involvement generally decreases with increasing age from the age of 25 years and onwards for both male and female road users at night time. Fatalities during night time were higher among young road users (20-34 years old) (55%, n= 1538) followed by middle-age road users (35-55 years old) (49%, n= 1169) and elderly road users (55 years and older) (40%, n=405). In terms of age and gender, males demonstrated higher frequencies of fatalities at night compared to females across all age groups (young males= 46%; young females=10%, middle-age males= 39%, middle-age females= 11%, elderly male=30% and elderly females=10%). Fatal injuries reach a peak for young male and female road users, with the age groups 20-24 (56%) and 25-29 (55%) reporting the highest number of fatalities for night time conditions, respectively. From the age of 30 years old, fatal injuries remain relatively high but gradually decrease. For middle-age road users, traffic fatalities are highest for the age group 35-39 (50%) and 40-44 (50%). For elderly road users, fatalities are highest in the age category 55-59 (47%).

4.2.8 RTFs according to road user category

The distribution of fatalities by road user category were analysed according to time of day and the results are shown in Figure 4-17.

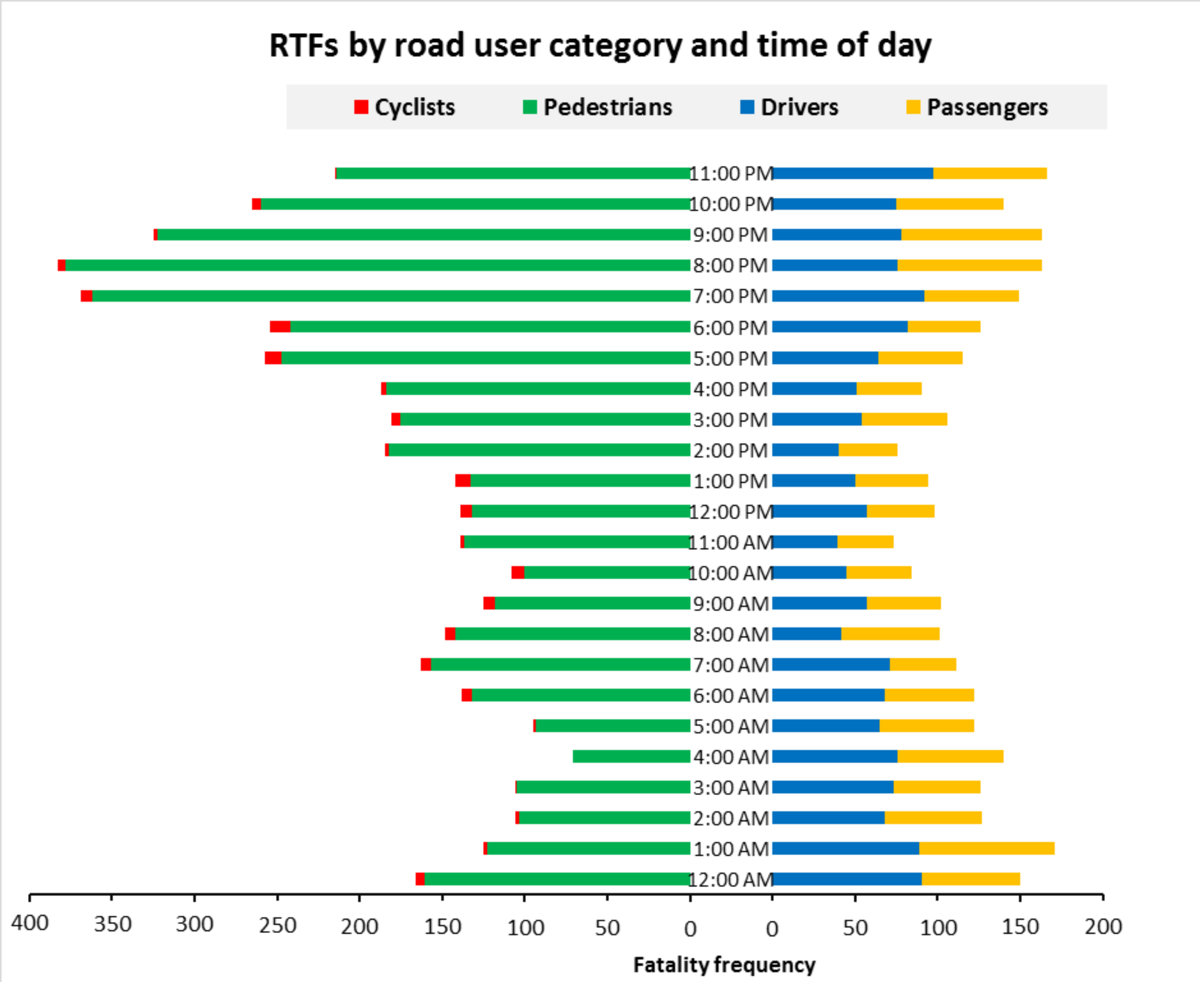


Figure 4-17: RTFs by road user category and time of day

The graph intends to highlight differences in fatal injuries between motorised transport modes (drivers and passengers) and non-motorised transport modes (pedestrians and cyclists) at night time. The category "driver" includes motorcyclists and car drivers and the category "passenger" includes motorcycle pillions and car passengers. Road user categories recorded as "other" were excluded from the analysis.

Overall, pedestrians make up the largest proportion of fatal crashes followed by drivers, passengers and cyclists. Except for cyclists, the number of traffic fatalities is higher at night time compared to daytime for all road users. Pedestrians (59%) make up the largest number of fatalities during night time followed by drivers (22%), passengers (18%) and cyclists (1%). The hour of the night time period with the highest number of traffic deaths for drivers is 11:00 PM (10%), 08:00 PM for pedestrians (15%), 06:00 PM for cyclists (26%) and 06:00 PM for passengers (11%).

4.2.8.1 Drivers

The distribution of RTFs according to driver age, gender and illumination condition are shown in Figure 4-18.

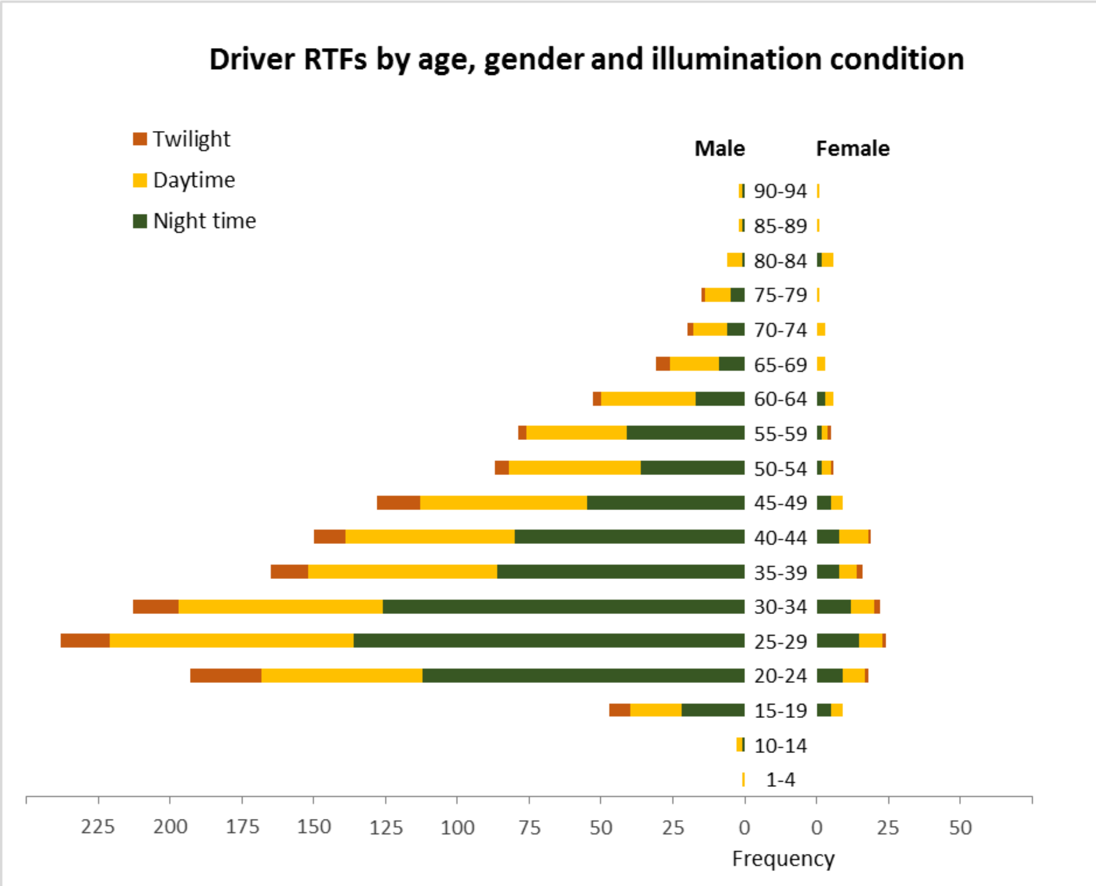


Figure 4-18: Driver RTFs by age, gender and illumination condition

From the age of 25 years old, fatalities among drivers appear to decline with increasing age for both males and females at night time. At night time, young drivers (15-34 years old) have the highest number of traffic deaths (54%) followed by middle-aged drivers (35-54 years old) (35%) and elderly drivers (55 years and older) (11%). While fatalities appear to be declining with increasing age at night, a peak in fatalities can be observed for male drivers between the ages of 55-59 and female drivers between the ages of 60-64 years old.

In terms of gender, male drivers demonstrate substantially higher fatalities relative to female drivers at night time. This trend was consistent for young drivers (male= 52% vs female= 5%), middle-age drivers (male= 44% vs female= 4%) and elderly drivers (male= 35% vs female = 3%).

Compared to daytime, traffic fatalities are higher at night time for young drivers (34% at daytime vs 57% at night time) and middle-age drivers (43% at daytime vs 48% at night time). Conversely, elderly drivers have higher traffic fatalities during daytime compared to night time (56% at daytime vs 38% at night time).

The ratio of night time to daytime driver RTFs were analysed by age and gender and the results for male drivers is shown in Table 4-3 and the results for female drivers is shown in Table 4-4.

Table 4-3: Male driver fatalities according to age and illumination condition

Age group	Daytime		Night time		Morn_Twilight		Eve_Twilight		Total		Night time-Day time ratio
	Count	%	Count	%	Count	%	Count	%	Count	%	
1-4	1	100.0%	0	0.0%	0	0.0%	0	0.0%	1	100%	0.00
10-14	2	66.7%	1	33.3%	0	0.0%	0	0.0%	3	100%	0.50
15-19	18	38.3%	22	46.8%	5	10.6%	2	4.3%	47	100%	1.22
20-24	56	29.0%	112	58.0%	19	9.8%	6	3.1%	193	100%	2.00
25-29	85	35.7%	136	57.1%	6	2.5%	11	4.6%	238	100%	1.60
30-34	71	33.3%	126	59.2%	8	3.8%	8	3.8%	213	100%	1.77
35-39	66	40.0%	86	52.1%	5	3.0%	8	4.8%	165	100%	1.30
40-44	59	39.3%	80	53.3%	5	3.3%	6	4.0%	150	100%	1.36
45-49	58	45.3%	55	43.0%	5	3.9%	10	7.8%	128	100%	0.95
50-54	46	52.9%	36	41.4%	3	3.4%	2	2.3%	87	100%	0.78
55-59	35	44.3%	41	51.9%	1	1.3%	2	2.5%	79	100%	1.17
60-64	33	62.3%	17	32.1%	1	1.9%	2	3.8%	53	100%	0.52
65-69	17	54.8%	9	29.0%	2	6.5%	3	9.7%	31	100%	0.53
70-74	12	60.0%	6	30.0%	2	10.0%	0	0.0%	20	100%	0.50
75-79	9	60.0%	5	33.3%	0	0.0%	1	6.7%	15	100%	0.56
80-84	5	83.3%	1	16.7%	0	0.0%	0	0.0%	6	100%	0.20
85-89	1	50.0%	1	50.0%	0	0.0%	0	0.0%	2	100%	1.00
90-94	1	50.0%	1	50.0%	0	0.0%	0	0.0%	2	100%	1.00
Total	**575**		**735**		**62**		**61**		**1433**		**1.28**

According to Table 4-3, traffic fatalities greater than 1 are predominant among young male drivers which indicate that these groups have higher fatalities at night time relative to daytime. The greatest disparity in fatalities during day and night time for young male drivers occur in the age group 20-34 years old, where fatalities during night time are exactly twice the number of fatalities during daytime. This was also the age category which showed the highest frequency of fatalities during night time relative to daytime. For middle-age male drivers, traffic fatalities are mainly higher at night time but generally decrease with advancing age. The greatest disparity in fatalities during day and night time for middle-age male drivers occur in the age group 30-34 years old, where fatalities during night time are almost twice the number (1.77) of fatalities during daytime. For elderly male drivers, traffic fatalities are predominantly lower at night except for the age group 55-59, where fatal crashes at night are slightly higher and the number of fatalities during night time is 1.17 times higher than the number of fatalities during daytime.

Table 4-4: Female driver fatalities according to age and illumination condition

Age group	Daytime		Night time		Morn_Twilight		Eve_Twilight		Total		Night time-Day time ratio
	Count	%	Count	%	Count	%	Count	%	Count	%	
15-19	4	44.4%	5	55.6%	0	0.0%	0	0.0%	9	100%	1.25
20-24	8	44.4%	9	50.0%	0	0.0%	1	5.6%	18	100%	1.13
25-29	8	33.3%	15	62.5%	0	0.0%	1	4.2%	24	100%	1.88
30-34	8	36.4%	12	54.5%	1	4.5%	1	4.5%	22	100%	1.50
35-39	6	37.5%	8	50.0%	0	0.0%	2	12.5%	16	100%	1.33
40-44	10	52.6%	8	42.1%	1	5.3%	0	0.0%	19	100%	0.80
45-49	4	44.4%	5	55.6%	0	0.0%	0	0.0%	9	100%	1.25
50-54	3	50.0%	2	33.3%	0	0.0%	1	16.7%	6	100%	0.67
55-59	2	40.0%	2	40.0%	1	20.0%	0	0.0%	5	100%	1.00
60-64	3	50.0%	3	50.0%	0	0.0%	0	0.0%	6	100%	1.00
65-69	3	100.0%	0	0.0%	0	0.0%	0	0.0%	3	100%	0.00
70-74	3	100.0%	0	0.0%	0	0.0%	0	0.0%	3	100%	0.00
75-79	1	100.0%	0	0.0%	0	0.0%	0	0.0%	1	100%	0.00
80-84	4	66.7%	2	33.3%	0	0.0%	0	0.0%	6	100%	0.50
85-89	1	100.0%	0	0.0%	0	0.0%	0	0.0%	1	100%	0.00
90-94	1	100.0%	0	0.0%	0	0.0%	0	0.0%	1	100%	0.00
Total	**69**		**71**		**3**		**6**		**149**		**1.03**

According to Table 4-4, similar to the trends observed for young male drivers, traffic fatalities greater than 1% occurs predominantly among young female drivers which indicates that this group has higher fatalities at night time relative to daytime. The greatest disparity in fatalities during day and night time for young female drivers occur in the age group 25-29 years old, where fatalities during night time for are almost twice the number of fatalities during daytime. This was also the age category which showed the highest frequency of fatalities during night time relative to daytime. For middle-age female drivers, traffic fatalities are mainly higher at night time and generally decrease with increasing age. The greatest disparity in fatalities during day and night time for middle-age female drivers occur in the age group 35-39 years old, where fatalities during night time are 1.33 times higher than the number of fatalities during daytime. For elderly female drivers, traffic fatalities are predominantly lower at night.

4.2.8.2 Pedestrians

The distribution of RTFs according to pedestrian age, gender and illumination condition are shown in Figure 4-19.

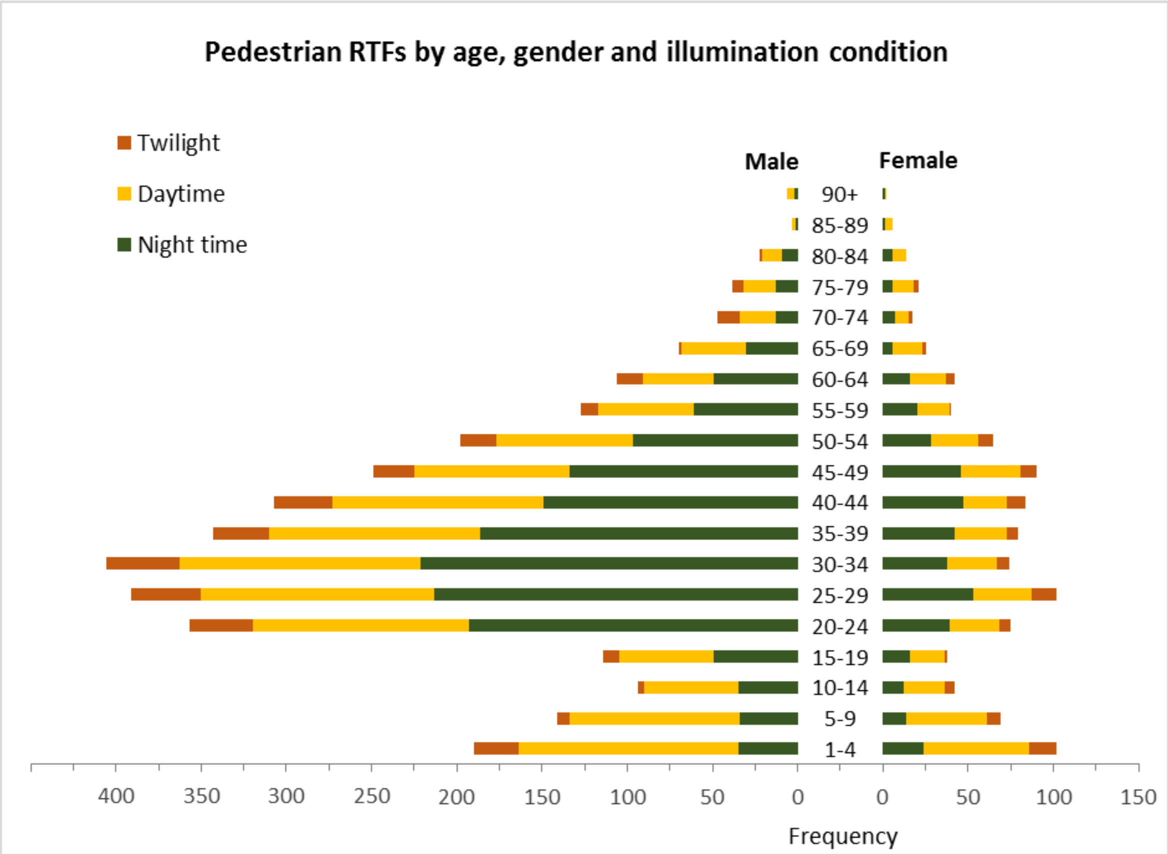


Figure 4-19: Pedestrian RTFs by age, gender and illumination condition

At night time, male pedestrian fatalities increase with advancing age until it reaches a peak in the 30-34 year age group. From this point onward, pedestrian fatalities gradually decline as age increases. A similar trend is observed for female pedestrian fatalities at night, with the exception of the peak in fatalities occurring in the 25-29 year age category for females. At night time, young pedestrians (15-34 years old) have the highest number of traffic deaths (42%) followed by middle-aged pedestrians (35-54 years old) (37%), elderly pedestrians (55 years and older) (12%) and child pedestrians (1-14 years old) (8%).

In terms of gender, male pedestrians demonstrate substantially higher fatalities relative to female pedestrians at night time. This trend was consistent for child pedestrians (male= 16% vs female= 8%), young pedestrians (male = 43% vs female = 9%), middle-age pedestrians (male= 40% vs female= 12%) and elderly pedestrians (male= 30% vs female = 11%).

Compared to daytime, traffic fatality rates are higher at night time for young pedestrians (37% at daytime vs 53% at night time) and middle-age pedestrians (38% at daytime vs 52% at night time). Conversely, higher traffic fatalities during daytime compared to night time were observed for child pedestrians (65% at daytime vs 24% at night time) and elderly pedestrians (49% at daytime vs 41% at night time).

The ratio of night time to daytime pedestrian RTFs were analysed by age and gender and the results for male pedestrians is shown in Table 4-5 and the results for female pedestrians are shown in Table 4-6.

Table 4-5: Male pedestrian fatalities according to age and illumination condition

Age group	Daytime		Night time		Morn_Twilight		Eve_Twilight		Total		Night time-Day time ratio
	Count	%	Count	%	Count	%	Count	%	Count	%	
1-4	129	67.9%	35	18.4%	0	0.0%	26	13.7%	190	100%	0.27
5-9	100	70.9%	34	24.1%	2	1.4%	5	3.5%	141	100%	0.34
10-14	55	58.5%	35	37.2%	0	0.0%	4	4.3%	94	100%	0.64
15-19	56	49.1%	49	43.0%	2	1.8%	7	6.1%	114	100%	0.88
20-24	127	35.6%	193	54.1%	15	4.2%	22	6.2%	357	100%	1.52
25-29	137	35.0%	213	54.5%	16	4.1%	25	6.4%	391	100%	1.55
30-34	142	35.0%	221	54.4%	22	5.4%	21	5.2%	406	100%	1.56
35-39	124	36.2%	186	54.2%	12	3.5%	21	6.1%	343	100%	1.50
40-44	124	40.4%	149	48.5%	14	4.6%	20	6.5%	307	100%	1.20
45-49	91	36.5%	134	53.8%	5	2.0%	19	7.6%	249	100%	1.47
50-54	80	40.4%	97	49.0%	5	2.5%	16	8.1%	198	100%	1.21
55-59	56	44.1%	61	48.0%	2	1.6%	8	6.3%	127	100%	1.09
60-64	42	39.6%	49	46.2%	4	3.8%	11	10.4%	106	100%	1.17
65-69	38	54.3%	30	42.9%	1	1.4%	1	1.4%	70	100%	0.79
70-74	21	44.7%	13	27.7%	6	12.8%	7	14.9%	47	100%	0.62
75-79	19	50.0%	13	34.2%	0	0.0%	6	15.8%	38	100%	0.68
80-84	12	54.5%	9	40.9%	0	0.0%	1	4.5%	22	100%	0.75
85-89	2	66.7%	1	33.3%	0	0.0%	0	0.0%	3	100%	0.50
90+	4	66.7%	2	33.3%	0	0.0%	0	0.0%	6	100%	0.50
Total	**1359**		**1524**		**106**		**220**		**3209**		**1.12**

According to Table 4-5, traffic fatalities greater than 1 occur predominantly among young and middle-age male pedestrians and to a lesser extent, elderly male pedestrians (55-64 years old). This indicates that these groups have higher fatalities at night time relative to daytime. For young male pedestrians, fatalities are predominantly higher at night and the greatest disparity in fatalities during day and night time occur in the age group 30-34 years old, where fatalities during night time are 1.56 times higher than the number of fatalities during daytime. This was also the age category which showed the highest frequency of fatalities during night time relative to daytime. For middle-age male pedestrians, traffic fatalities are mainly higher at night time but generally decrease with advancing age. The greatest disparity in fatalities during day and night time for middle-age male pedestrians occur in the age group 35-39 years old, where fatalities during night time are 1.5 times higher than the number of fatalities during daytime. For elderly male pedestrians, traffic fatalities are for the most part, lower at night. However, fatalities at night time are higher than the number of fatalities during night time for the age category 50-54 years old (1.09) and the age category 60-64 years old (1.17). For child male pedestrians, traffic fatalities are consistently lower at night.

Table 4-6: Female pedestrian fatalities according to age and illumination condition

Age group	Daytime		Night time		Morn_Twilight		Eve_Twilight		Total		Night time-Day time ratio
	Count	%	Count	%	Count	%	Count	%	Count	%	
1-4	62	60.8%	24	23.5%	1	1.0%	15	14.7%	102	100%	0.39
5-9	47	68.1%	14	20.3%	2	2.9%	6	8.7%	69	100%	0.30
10-14	24	57.1%	12	28.6%	1	2.4%	5	11.9%	42	100%	0.50
15-19	20	52.6%	16	42.1%	0	0.0%	2	5.3%	38	100%	0.80
20-24	29	38.7%	39	52.0%	4	5.3%	3	4.0%	75	100%	1.34
25-29	34	33.3%	53	52.0%	8	7.8%	7	6.9%	102	100%	1.56
30-34	29	39.2%	38	51.4%	5	6.8%	2	2.7%	74	100%	1.31
35-39	31	39.2%	42	53.2%	0	0.0%	6	7.6%	79	100%	1.35
40-44	26	31.0%	47	56.0%	4	4.8%	7	8.3%	84	100%	1.81
45-49	35	38.9%	46	51.1%	7	7.8%	2	2.2%	90	100%	1.31
50-54	28	43.1%	28	43.1%	3	4.6%	6	9.2%	65	100%	1.00
55-59	19	47.5%	20	50.0%	1	2.5%	0	0.0%	40	100%	1.05
60-64	21	50.0%	16	38.1%	2	4.8%	3	7.1%	42	100%	0.76
65-69	17	68.0%	6	24.0%	0	0.0%	2	8.0%	25	100%	0.35
70-74	8	47.1%	7	41.2%	0	0.0%	2	11.8%	17	100%	0.88
75-79	12	57.1%	6	28.6%	2	9.5%	1	4.8%	21	100%	0.50
80-84	8	57.1%	6	42.9%	0	0.0%	0	0.0%	14	100%	0.75
85-89	5	83.3%	1	16.7%	0	0.0%	0	0.0%	6	100%	0.20
90+	1	50.0%	1	50.0%	0	0.0%	0	0.0%	2	100%	1.00
Total	**456**		**422**		**40**		**69**		**987**		**0.93**

Similar to the trends observed for male pedestrians, traffic fatalities greater than 1% are predominant for young and middle-age female pedestrians and to a lesser extent, elderly female pedestrians (55-59 years old). This indicates that these groups have higher fatalities at night time relative to daytime. For young female pedestrians, fatalities are predominantly higher at night and the greatest disparity in fatalities during day and night time occur in the age group 25-29 years old, where fatalities during night time are 1.56 times higher than the number of fatalities during daytime. For middle-age female pedestrians, traffic fatalities are mainly higher at night time but generally decrease with advancing age. The greatest disparity in fatalities during day and night time for middle-age female pedestrians occurs in the age group 40-44 years old, where fatalities during night time are 1.81 times higher than the number of fatalities during daytime. This was also the age category which showed the highest frequency of fatalities during night time relative to daytime. For elderly female pedestrians, traffic fatalities are for the most part, lower at night. However, fatalities at night time are higher than the number of fatalities during night time for the age category 55-59 years old (1.05). For child female pedestrians, traffic fatalities are consistently lower at night.

4.2.9 RTFs according to race

The distribution of RTFs according to race and time of day for motorists and non-motorists are shown in Figure 4-20.

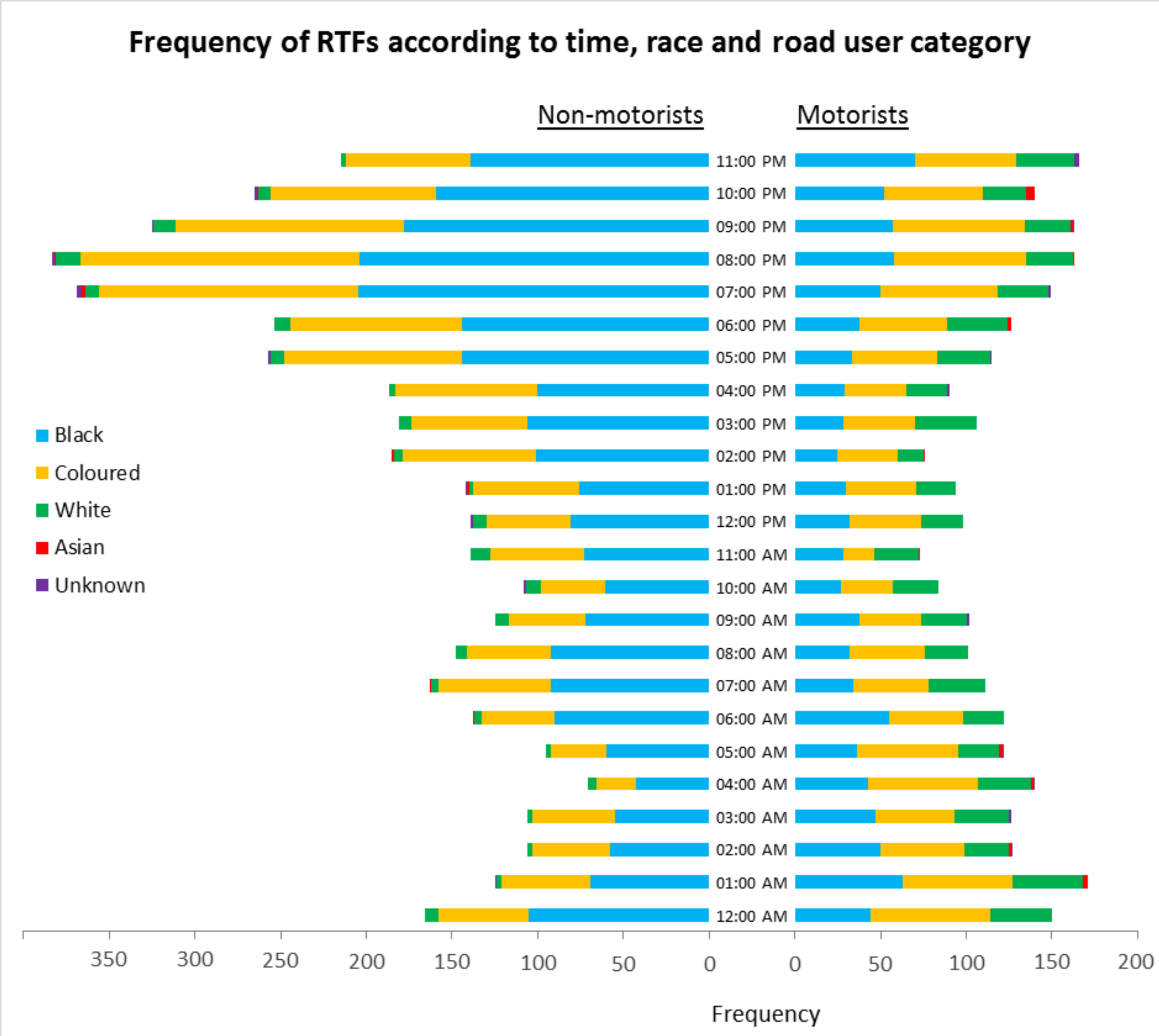


Figure 4-20: RTFs by race, road user category and time of day among motorised and non-motorised road users

For drivers at night time, coloured drivers have the highest number of traffic deaths (43%) followed by black drivers (35%), white motorists (21%) and Asian drivers (1%). Compared to daytime, traffic fatalities are higher at night time for all race groups with Asian drivers demonstrating the greatest difference in fatalities between day and night time (8% at daytime vs 84% at night time), followed by coloured drivers (35% at daytime vs 58% at night time), black drivers (36% at daytime vs 57% at night time) and white drivers (43% at daytime vs 50% at night time).

For non-motorised road users at night time, black NMT users have the highest number of traffic deaths (57%) followed by coloured NMT users (39%), white motorists (3%) and Asian drivers (1%). Compared to daytime, traffic fatalities are higher at night time for all race groups with similar differences in fatalities between day and night time shown for coloured (43% at daytime vs 57% at night time) and black (43% at daytime vs 57% at night time) NMT road users and Asian (50% at daytime vs 50% at night time) and white (49% at daytime vs 51% at night time) NMT road users.

4.3 Analysis of Naturalistic Driving Videos

4.3.1 Participant characteristics

Four drivers were recruited to participate in the study. A larger sample of drivers would be more advantageous as it would yield more reliable results but due to limitations in the equipment available to collect data, only four drivers were able to participate in the study (Venter, 2014). The characteristics of participants in terms of gender, age and driving experience are shown in Table 4-7.

Table 4-7: Characteristics of participants in naturalistic driving videos

Participants characteristics				
	Novice Driver 1	**Novice Driver 2**	**Experienced Driver 1**	**Experienced Driver 2**
Gender	Male	Female	Female	Male
Age	20 years old	19 years old	41 years old	53 years old
Driving Experience	6 months	4 months	20 years	30 years

Source: Venter (2014)

4.3.2 Driving videos information

4.3.2.1 Length of driving videos recorded during the study period

Table 4-8 provides detail on the number of driving video hours recorded for the entire study period. In total, 255 hours of driving videos were recorded. Novice driver 1 and experienced drivers 1 generated the most videos and this was attributed to these drivers living further away from their respective places of work and study which resulted in additional travel time.

Table 4-8: Length of driving video hours recorded during study period (hours)

Number of hours driven during study period	
Driver Type	**Total**
Novice Driver 1	35.7
Novice Driver 2	82
Experienced Driver 1	113.9
Experienced Driver 2	23.73
Total number of hours	**255**

Source: Venter (2014)

4.3.2.2 Length of driving video coded for night driving

Table 4-9 provides detail on the number of driving video hours coded for night driving. All the videos obtained from the Department of Civil Engineering at Stellenbosch University were coded and this amounted to 8.2 hours of driving videos. Novice driver 1 and experienced driver 1 generated the most video time for night driving. The driving videos for each participant record drivers navigating various roads and traffic facilities, although the time spent at various roads and facilities vary according to participants.

Table 4-9: Length of video hours coded for night driving (hours)

Number of hours coded for night driving	
Driver Type	**Number of hours**
Novice Driver 1	1.9
Novice Driver 2	2.4
Experienced Driver 1	2.2
Experienced Driver 2	1.9
Total number of hours	**8.4**

Table 4-10: Length of videos coded for night driving (km)

Number of hours coded for night driving	
Driver Type	**Number of km**
Novice Driver 1	107
Novice Driver 2	224.2
Experienced Driver 1	179.4
Experienced Driver 2	131
Total number of km's	**641.6**

4.3.3 Speed behaviour at night

Speed data was retrieved by analysing video frames that were extracted every five seconds from the driving video. The speed recording was documented on an Excel spreadsheet according to road type, among other variables. The average speed for each road type was calculated by adding up all the values of the speed recordings obtained from the five second video frames and dividing this by the number of speed recordings analysed.

Table 4-11 shows the number of hours and the number of driving events according to each road type on which the speed data is based.

Table 4-11: Number of drives and hours spent on various roads

Road Type	**Novice Drivers (n= 2)**		**Experienced Drivers (n= 2)**	
	Number of hours	Number of driving events	Number of hours	Number of driving events
Freeway (120 km/h)	2.2	7	1.9	6
Rural road (100 km/h)	1.2	5	1.1	6
Rural road (80 km/h)	0.6	4	0.5	3
Urban road (60 km/h)	0.2	6	0.4	8
Residential road (60 km/h)	0.1	8	0.2	9

More driving events took place on freeways and rural roads as opposed to urban roads. Based on the speeds derived from these driving events, the following sections provide an analysis of average and maximum speed at night and in the presence and absence of street lighting.

4.3.3.1 Average and maximum speeds at night

The average speed and maximum speeds according to road type for the two novice and two experienced drivers at night are shown in Figure 4-21 and Table 4-12.

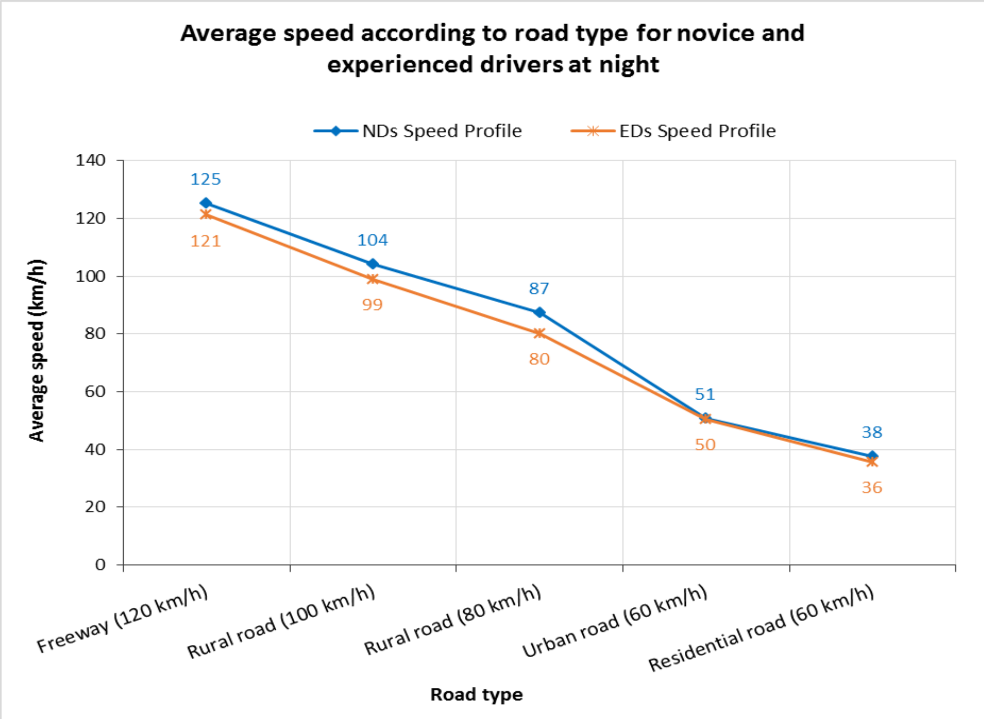


Figure 4-21: Average speed according to road type for novice and experienced drivers at night

Table 4-12: Average and maximum speeds for novice and experienced drivers at night

Road Type	**Novice Drivers (n= 2)**		**Experienced Drivers (n= 2)**	
	Average Speed (km/h)	Maximum Speed (km/h)	Average Speed (km/h)	Maximum Speed (km/h)
Freeway (120 km/h)	125	137	121	135
Rural road (100 km/h)	104	117	99	109
Rural road (80 km/h)	87	110	80	89
Urban road (60 km/h)	51	59	50	61
Residential road (60 km/h)	38	57	36	50

The two novice drivers adopted higher speeds than the two experienced drivers across all road types. Novice drivers adopted average speeds above the speed limit on freeways (125 km/h), on 100 km/h rural roads (104 km/h) and on 80 km/h rural roads (87 km/h). While the experienced drivers did not greatly exceed the speed limit on the various roads, the speeds adopted by these drivers closely approximate the posted speed of the roads in question (121 km/h on freeways, 99 km/h on 100 km/h rural roads and 80 km/h on 80 km/h rural roads).

4.3.3.2 Average and maximum speeds at day and night time

Speed choice at day and night time was also compared. Analysing the novice and experienced driver's speed at night time relative to daytime was deemed important to determine if and to what extent drivers change their speed under conditions of darkness. Driving videos for daytime conditions were not available to extract speed data and analyse speed behaviour. However, average and maximum speed under daytime illumination was analysed for novice and experienced drivers by Venter (2014). Average and maximum speed values were documented in her study and these values were plotted along speed data for night time to examine the relationship between driver speed choice and illumination condition. Only speed data for freeways (120 km/h), rural roads (80 km/h), urban roads (60 km/h) and residential roads (60 km/h) were used in the analysis since no data for 100 km/h rural roads was documented in her study. Although Venter (2014) does not specify the number of drives or the number of hours on which the daytime speeds according to road type is based on, in sum, the total number of daytime video hours amounted to 8.2 which is similar to the length of night time videos coded in this study. The minimal difference between the length of night time and daytime driving video coded makes it, to a certain degree possible to compare speeds since the length of videos are similar and the possibility of getting higher or lower speeds due to more or less speed recordings is mitigated.

In addition to assessing speed behaviour under different illumination conditions, the main advantage of comparing speed behaviour at day and night time is that behaviour under different illumination conditions are analysed for the same drivers. Some studies have reported vast differences in speed behaviour under day and night time conditions. While these results do indicate differences in speed choice under varying conditions of illumination, a common concern frequently raised is that different driver populations may occupy the roads at night which introduces biases and the use of non-representative sample populations and ultimately skewed results. Drivers occupying the roads at night time, and especially during the later hours of the night time period, commonly tend to be young males, with a predisposition towards risk-taking and sensation-seeking and drivers that generally adopt higher average speeds (Williams, 1985). These traits may not characterise the daytime driver population which means that when comparing average speeds at day and night time, different subgroups of drivers are essentially being compared (Assum *et al.*, 1999). This difficulty is overcome in this study by comparing the speed behaviour of the same driver at daytime and night time.

The results for driver speed on various roads at day and night time is shown in Figure 4-22 and Figure 4-23.

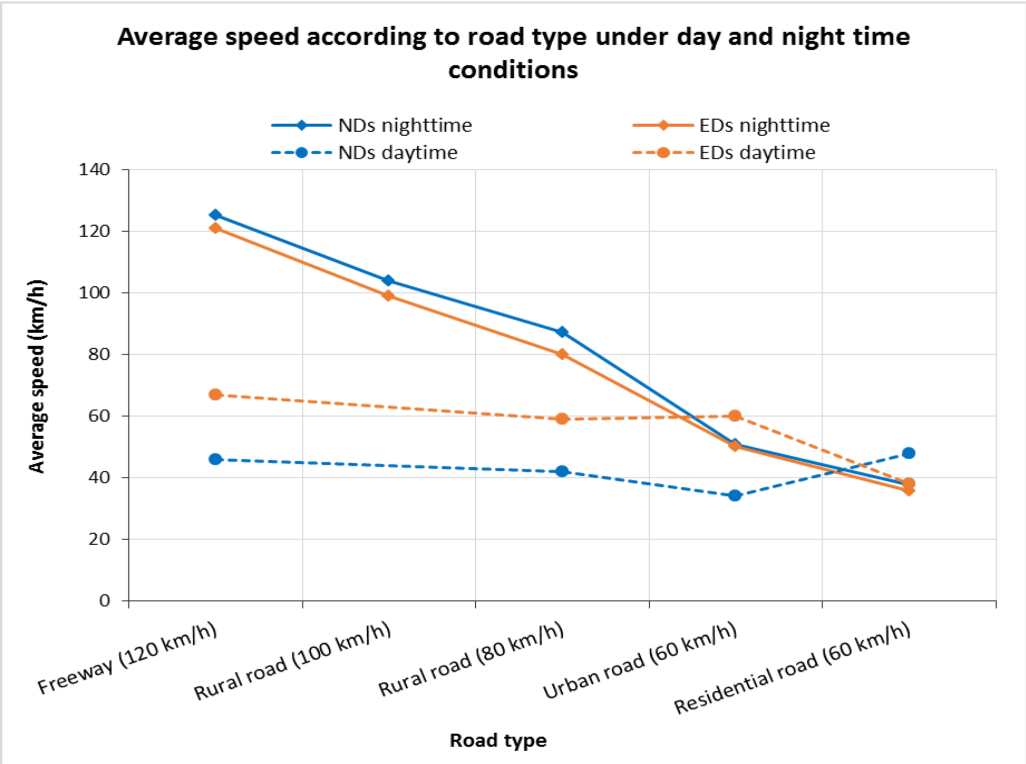


Figure 4-22: Average speed according to road type under day and night time conditions

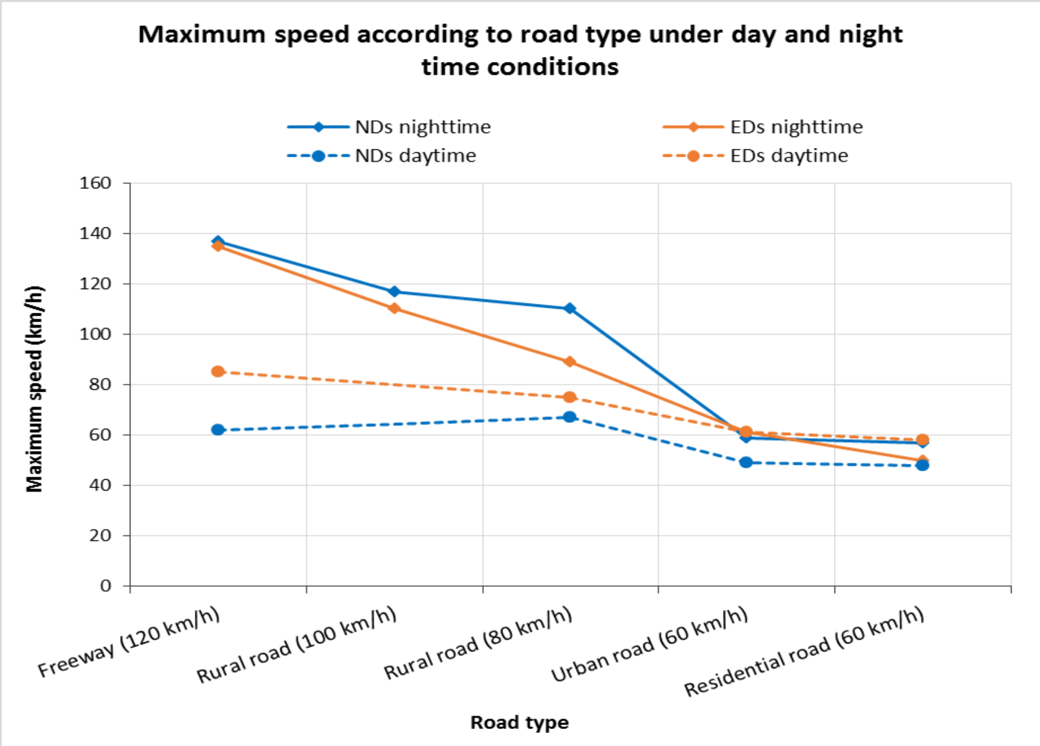


Figure 4-23: Maximum speed according to road type under day and night time conditions

The results show that the drivers in this study adopted significantly higher speeds at night time compared to daytime. The daytime speed data retrieved from the study by Venter (2014) were strikingly low even for daytime conditions. While these surprising findings were acknowledged by the author, no reasons were provided for these extraordinarily low speeds. The low speeds observed during daytime conditions may attributed to the effect of traffic congestion since participants drove during daytime and may have primarily driven during peak commuting hours in the morning and evening.

Generally, the speed chosen by the novice drivers at night time was twice as high as the speed chosen during daytime. This was observed for all roads except urban and residential roads. Relative to daytime, the speeds adopted at night time was twice as high for the novice drivers and almost twice as high for the experienced drivers. The greatest difference in speed for day and night time conditions was observed on freeways. Night time speeds surpassed daytime speeds on all roads except urban and residential roads. On these roads, drivers appear to have chosen higher speeds during the daytime compared to night time. These findings are somewhat counter-intuitive since it is expected that traffic volumes would be higher in urban and residential roads during the day which would cause drivers to drive more slowly. During daytime, experienced drivers drove faster than novice drivers but at night the opposite trend was observed with novice drivers' driving faster than experienced drivers. The greatest increase in speed between day and night time was observed for novice drivers.

4.3.3.3 Speed behaviour under different lighting conditions on 100 km/h rural roads

Speed behaviour under different lighting conditions was also analysed between the two novice and two experienced drivers. Most of the roadway on rural roads (100 km/h roads and 80 km/h roads) consisted of drivers passing through roads with no street lighting. During these times, vehicle headlights from their own vehicles and passing vehicles provided illumination. There were some occasions when drivers would pass through a section of the road that is illuminated by street lighting (although it was typically less than 10 km's). Data was collected on speed behaviour during this period to investigate differences in speeds before entering the road section with street lighting (before illumination), while passing through the road section with street lighting (through illumination) and when leaving the road section with street lighting, i.e. returning to the non-illuminated road section (after illumination). Average speed was obtained from the data and the results are shown in Figure 4-24 and Figure 4-25.

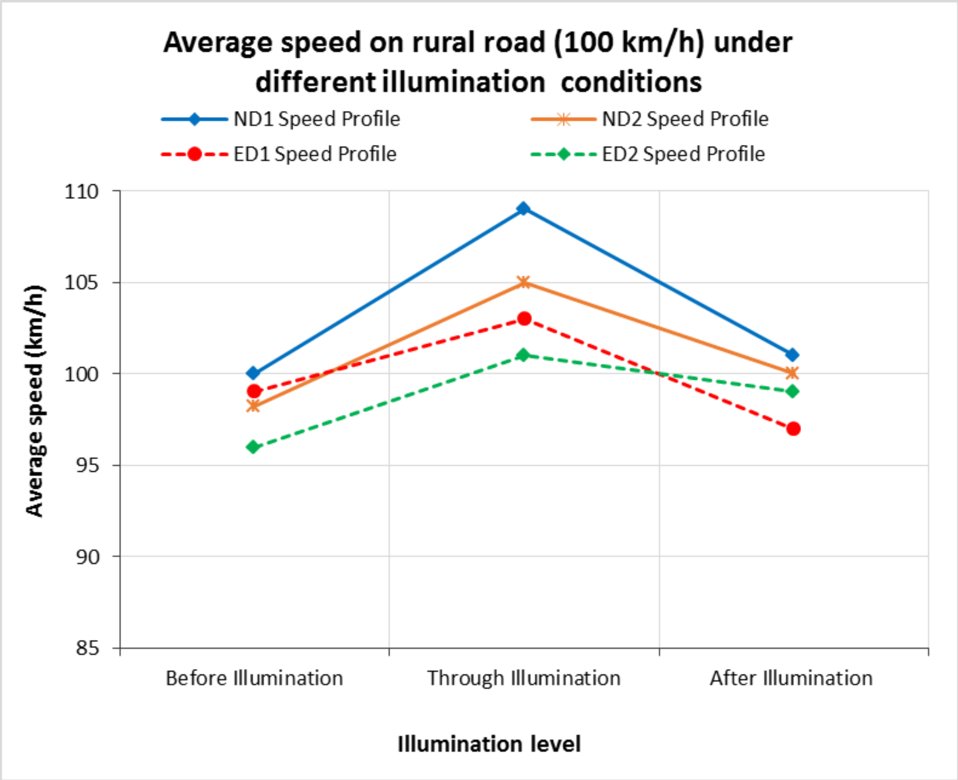


Figure 4-24: Average speed on rural roads (100 km/h) for all drivers under different illumination conditions

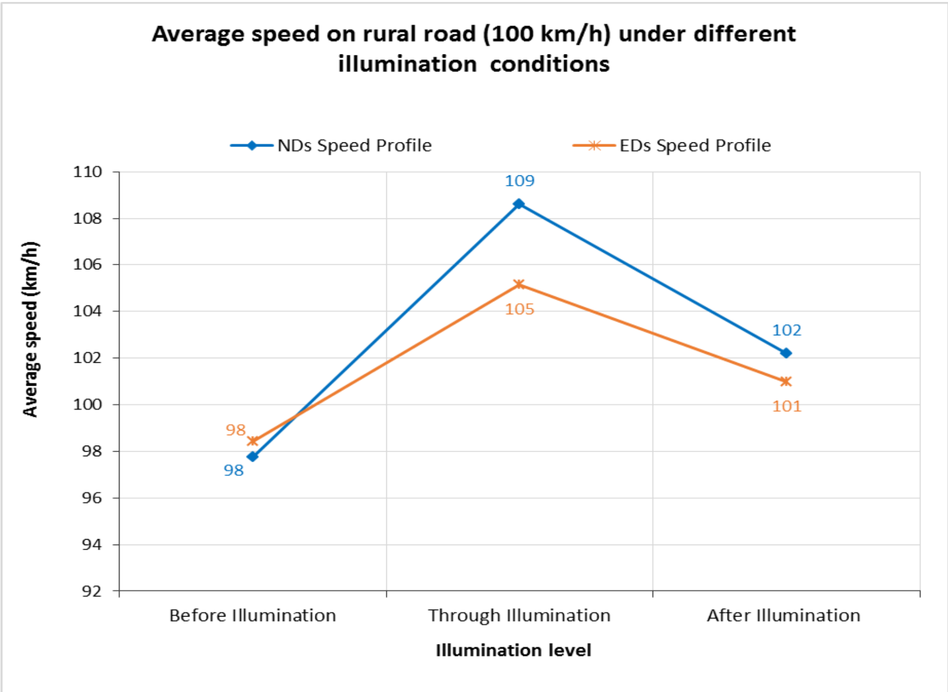


Figure 4-25: Comparison of novice and experienced drivers average speed on rural roads (100 km/h) under different illumination conditions

According to Figure 4-24 and Figure 4-25, the drivers in this study demonstrated an increase in speed when travelling through the illuminated road section but the increase in speed was more pronounced among the novice drivers than the experienced drivers. According to Figure 4-25, before illumination, average driver speed closely approximates the speed limit at 98 km/h for both driver groups. Upon entering the illuminated road section, speed increased to 11 km/h higher than the posted speed limit for the novice drivers and 7 km/h higher for the experienced drivers. Following the illuminated road section, speed for both driver groups steadily decreased to speeds adopted before entering the illuminated section. These results demonstrate that the drivers in this study responded to enhancements in roadway illumination by increasing their speed.

4.3.3.4 Speed behaviour under different lighting conditions on 80 km/h rural roads

Speed behaviour under different lighting conditions was also analysed between the novice and experienced drivers on 80 km/h rural roads. As with 100 km/h rural roads, average speed before, during and after illumination were analysed and the results are displayed in Figure 4-26 and Figure 4-27.

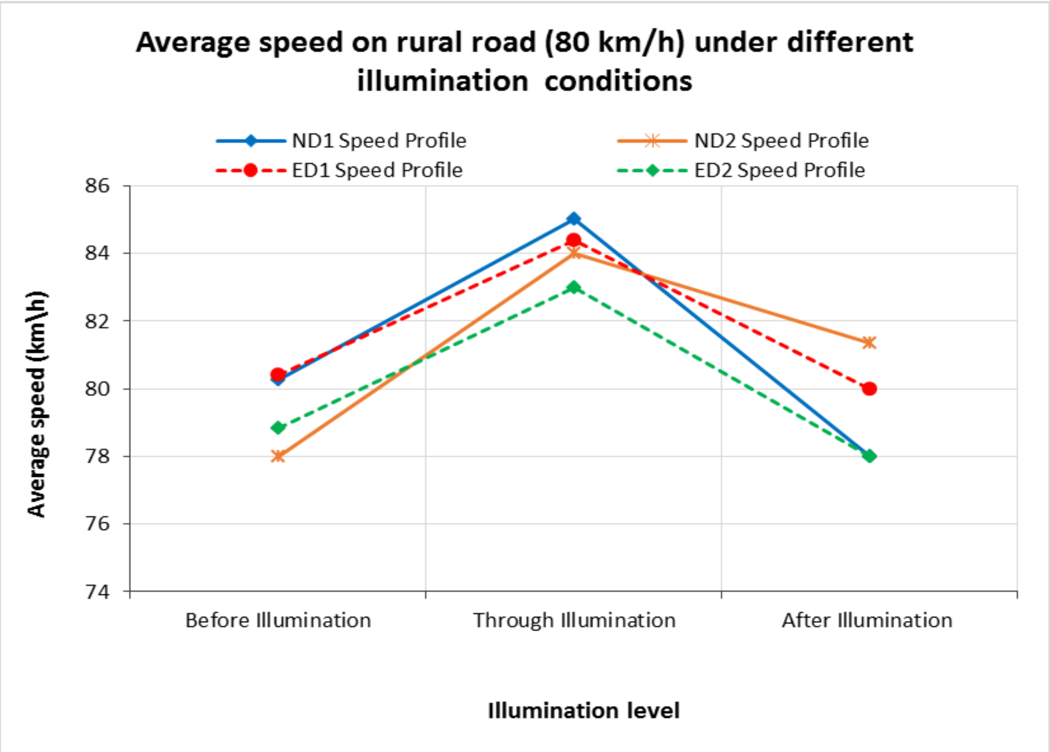


Figure 4-26: Average speed on rural roads (80 km/h) under different illumination conditions

According to these graphs, average speed for the four drivers increases during illuminated road sections. This is similar to the average speed trends observed on 100 km/h rural roads with street illumination, although the increments in speed on 80 km/h rural roads are not as high as those observed for 100 km/h rural roads. Another similarity between 80 km/h and 100 km/h rural roads is that the novice drivers select higher speeds than the experienced drivers.

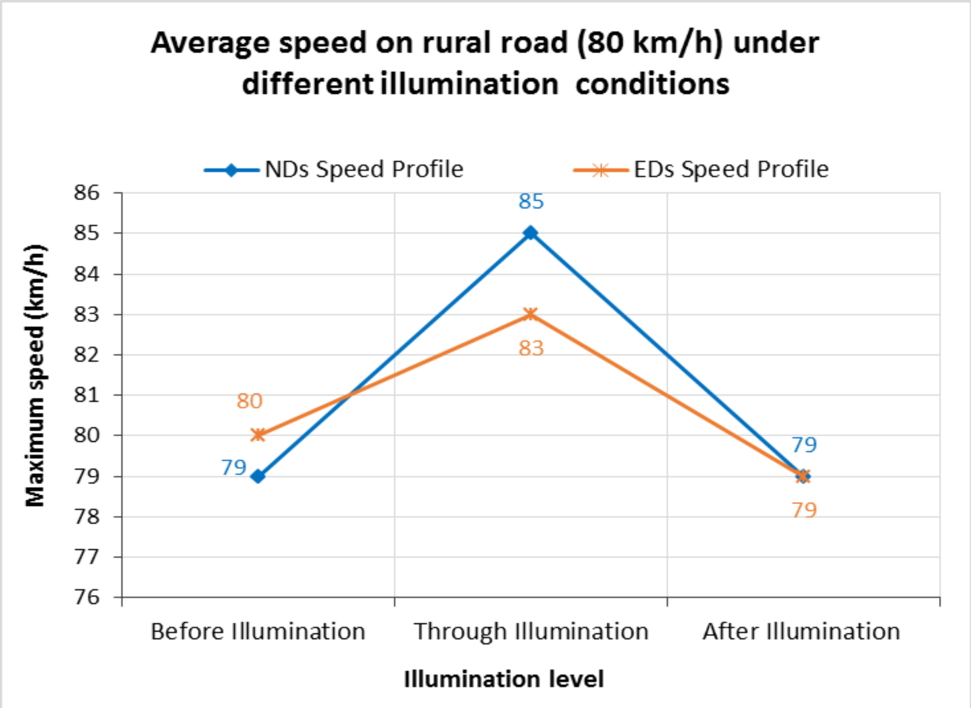


Figure 4-27: Comparison of novice and experienced drivers average speed on rural roads (80 km/h) under different illumination conditions

4.3.3.5 Speed violations

Based on the speed data collected on various roads, it was possible to determine the frequency of speeding violations among the two novice and two experienced drivers. According to Figure 4-28, the drivers in this study commonly exceeded the speed limit by 1-10 km/h. Furthermore, the novice drivers violated the speed limit by 11-20 km/h and >30 km/h more frequently while the experienced drivers violated the speed limit by 1-10 km/h and 21-30 km/h more frequently.

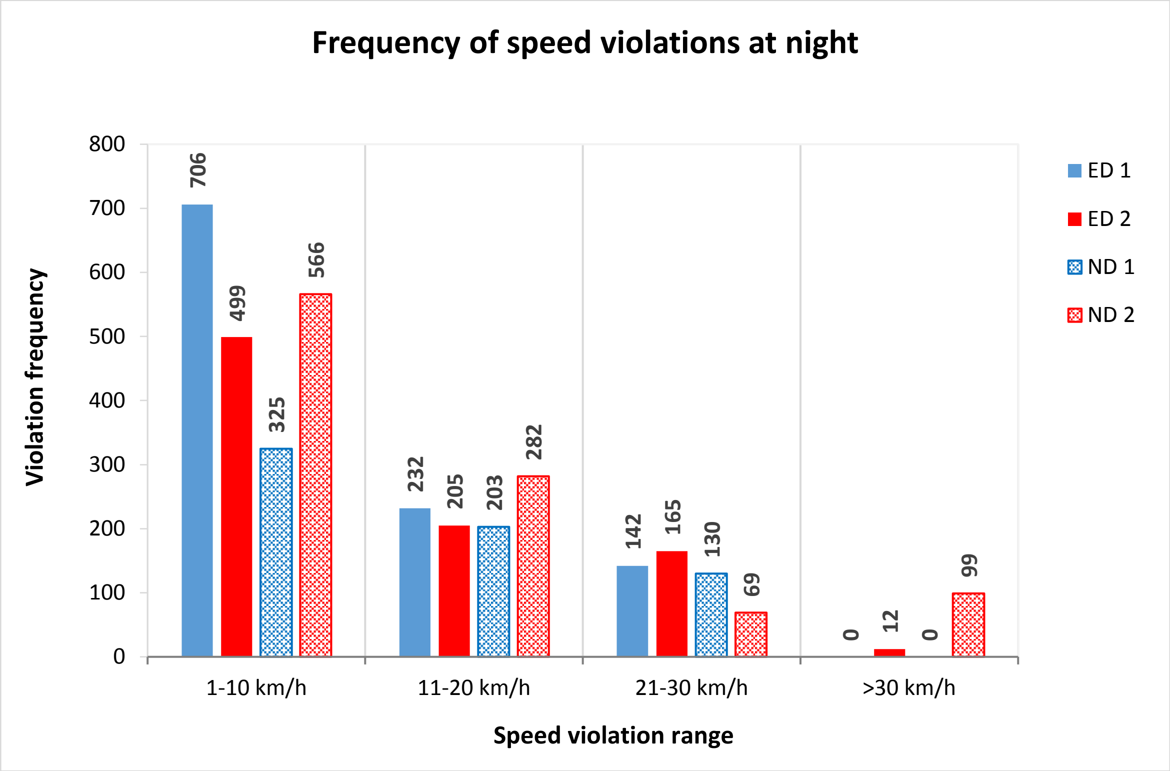


Figure 4-28: Frequency of speed violations at night among novice and experienced drivers

4.3.4 Intersection behaviour at night

Gaze behaviour at various intersections was examined at night time and glance frequency and duration was recorded at each intersection. Glance frequency refers to the number of times the drivers looked in a particular direction (left, right, left mirror, right mirror, straight ahead, and rear-view mirror). Glance duration refers to the time spent scanning a particular direction. It is recorded from the time the driver directs their gaze/ head in one direction and ends when the driver shifts their gaze/head in another direction. The glance frequency and duration at different intersections were recorded and the average glance frequency and glance duration was determined. Table 4-13 shows the number of intersections at which gaze behaviour was examined with the corresponding speed limits for the two novice and two experienced drivers.

Table 4-13: Intersection type and speed limit for novice and experienced drivers

Road Type	Speed limit (km/h)	Novice Drivers (n= 2)	Experienced Drivers (n= 2)
Stop-sign controlled intersection	60	11	12
Traffic light (red)	60	3	2
Traffic light (amber)	60	2	3
Traffic light (green)	60	4	4
T-junction (entering a minor road)	80	5	5
T-junction (entering a major road)	80	8	8

4.3.4.1 Intersection approach speed

Intersection approach speed was recorded for drivers at the intersections shown in Table 4-13. The average intersection approach speed is shown Figure 4-29.

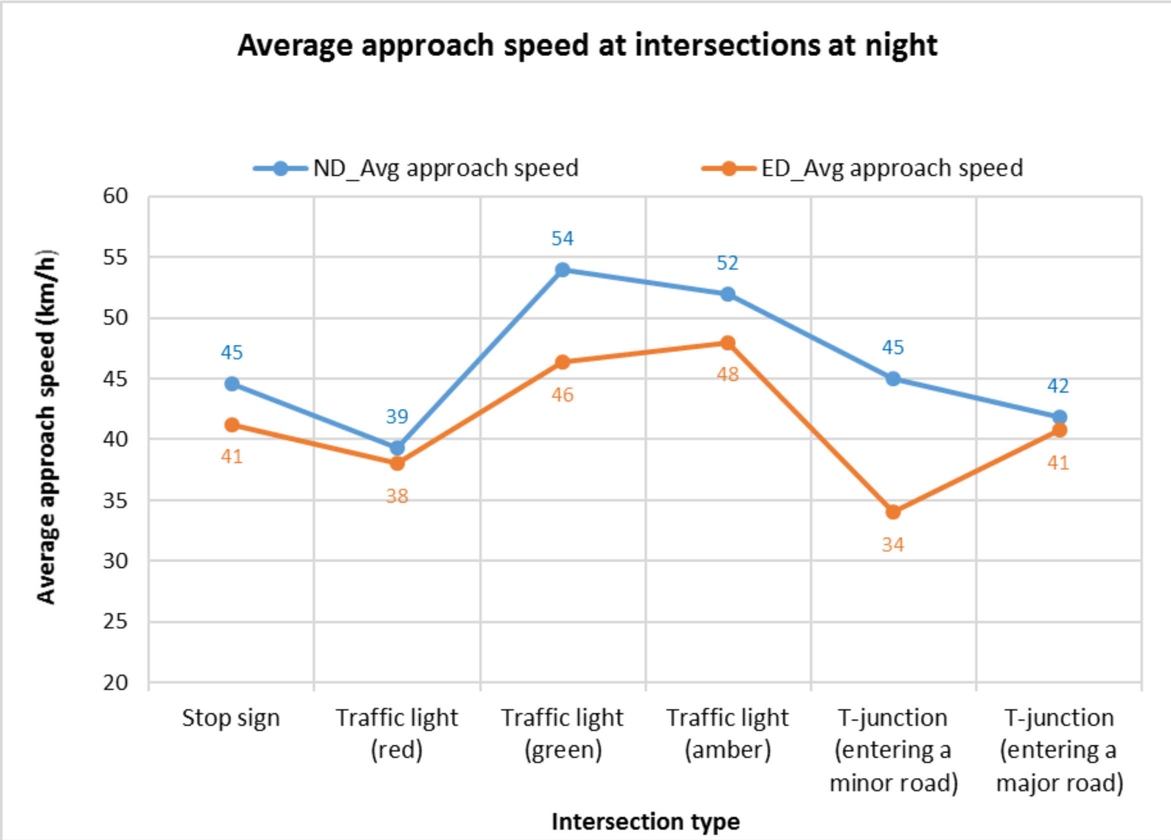


Figure 4-29: Average approach speed at intersections at night

For all the intersections analysed, the approach speed of the novice drivers was consistently higher than the approach speeds of the experienced drivers. For the novice drivers, average speeds were higher when approaching a green traffic signal and an amber traffic signal. The experienced drivers also adopted higher average speeds when approaching green and amber traffic lights.

Intersection approach speed was also analysed under different lighting conditions to determine whether drivers adjust their speed at intersections when street light is absent. For this analysis, approach speed was analysed at lit and unlit stop sign controlled intersections and T-junctions (entering a minor road and entering a major road). No data was available for approach speed at unlit traffic lights since these facilities are typically illuminated. The results from the analysis are displayed in Figure 4-30.

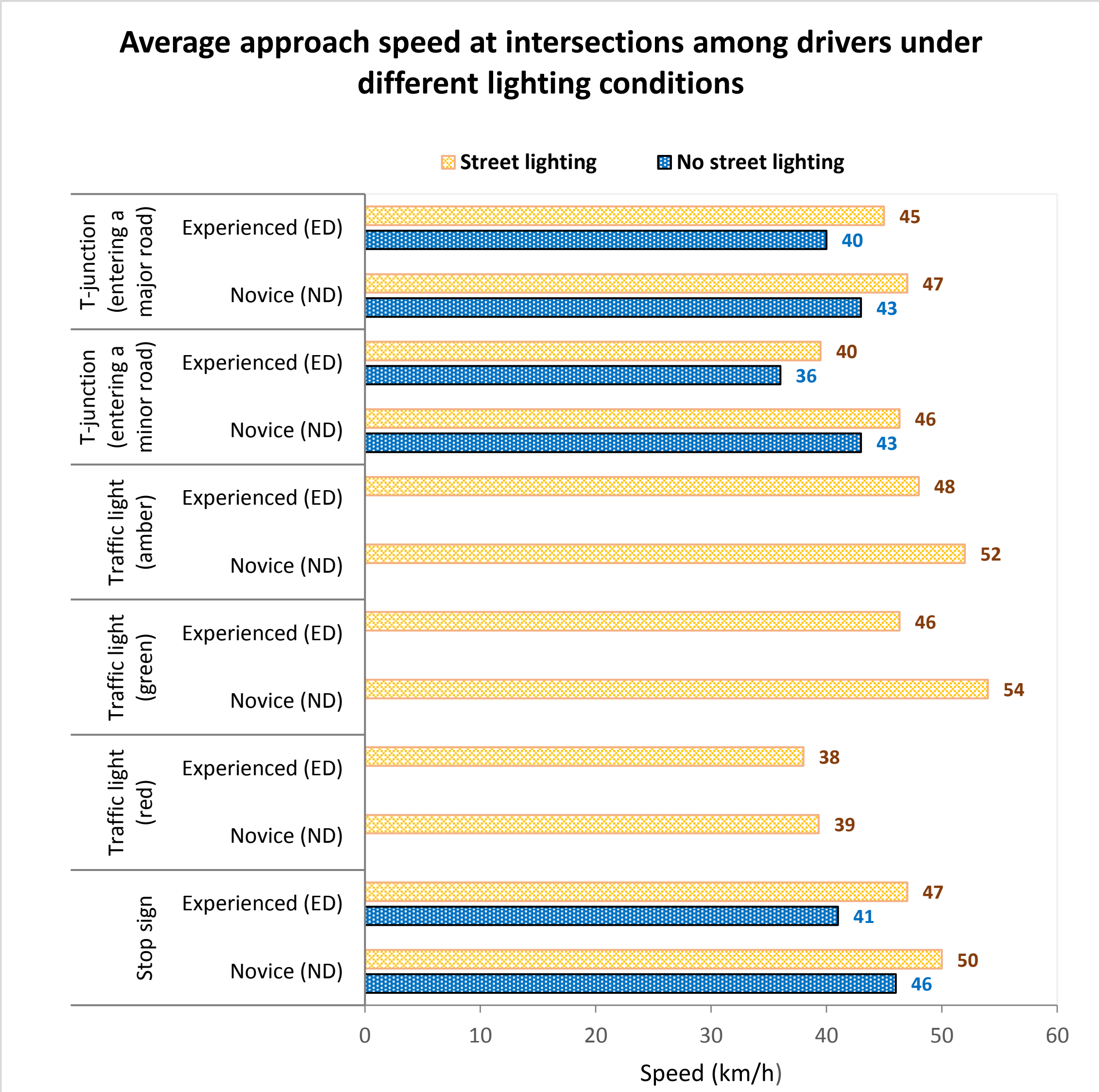
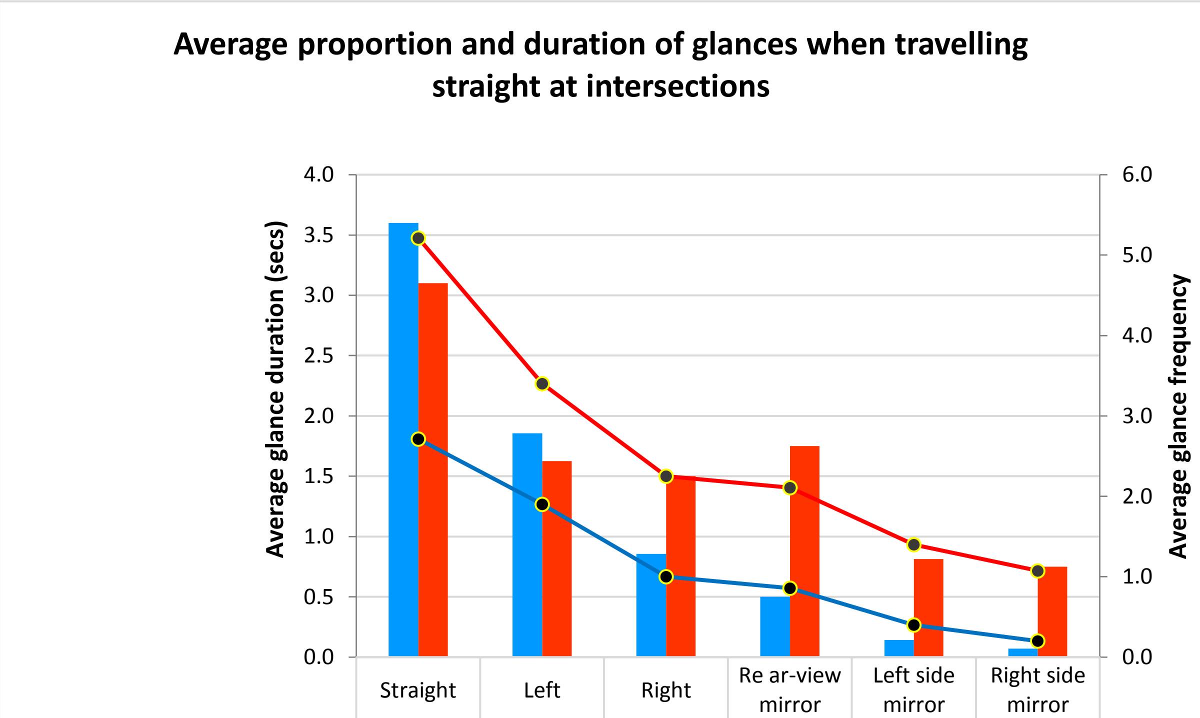


Figure 4-30: Average approach speed at intersections under different lighting conditions

According to the graph, a decrease in average approach speed at intersections can be observed for both the novice and experienced drivers. The greatest reduction in approach speed was made by the experienced drivers. The highest decrease in speeds on approach to unlit intersections for the experienced drivers was 6 km/h which occurred at stop-sign controlled intersections. In contrast, the highest decrease in speeds on approach to unlit intersections for novice drivers was 4 km/h which also occurred at stop-sign controlled intersections.

4.3.4.2 Gaze behaviour at intersections at night

Gaze behaviour at intersections was analysed for the novice and experienced drivers during straight-through, left turn and right turn driving manoeuvres. At each intersection and for each driving manoeuvre, the glance frequency (number of times the drivers looked in a particular direction such as left, right, left mirror, right mirror, straight ahead, and rear-view mirror) and glance duration (the time spent scanning a particular direction) was recorded. Glance duration was recorded from the time the driver directed their gaze/ head in one direction and ended when the driver shifted their gaze/head in another direction. The results are shown in Figure 4-31, Figure 4-33 and Figure 4-32 and are analysed collectively to identify the visual search strategies the novice and the experienced drivers used at intersections at night.



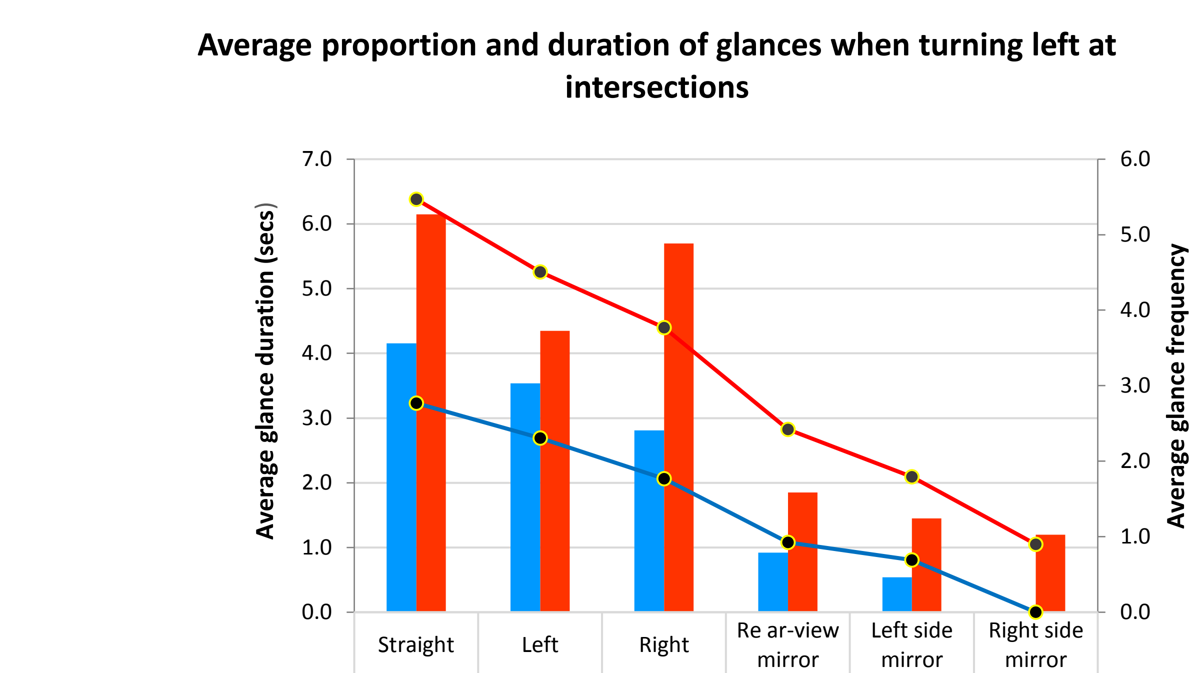
	Straight	Left	Right	Re ar-view mirror	Left side mirror	Right side mirror
Average duration for ND	3.6	1.9	0.9	0.5	0.1	0.1
Average duration for ED	3.1	1.6	1.5	1.8	0.8	0.8
Average frequency for ED	2.5	1.5	1.3	1.3	1.0	0.9
Average frequency for ND	2.7	1.9	1.0	0.9	0.4	0.2

Figure 4-31: Average proportion and duration of glances when travelling straight at intersections

For straight through manoeuvres, average glance frequency and glance duration was higher for the experienced drivers (8.4 and 10.1 s, respectively) compared to the novice drivers (6.7 and 7.0 s respectively). The novice drivers predominantly allocated their attention to the straight (51%) and left directions (27%). While the novice drivers did check the mirrors (rear-view mirror and left and right side mirror), the average frequency (1.1) and average duration of glances (0.7 s) in these directions were small. Except for straight and left glances, the graph and table attached to the graph also show that the average duration of glances generally tends to be lower than the average proportion of glances. This suggests that the novice drivers in this study do give visual attention to the other directions but that these glances tend to be shorter and swift glances. Thus, these drivers do direct their gaze to the different directions but the time allocated to the direction tends to be shorter.

For the experienced drivers, similar to the novice drivers visual attention for straight through manoeuvres was mostly allocated in the straight (36%) and left (16%) direction. However, unlike the novice drivers, the experienced drivers tend to also allocate more attention to the mirrors. The average frequency and average duration of glances for the mirrors was 3.2 and 3.4 s respectively. In terms of mirror-checking, the average glance frequency among the experienced drivers was almost three times higher than that of the novice drivers and the average glance duration was almost five times higher than that of the novice drivers. The graph and table attached also shows that the frequency of glances (8.4) is slightly smaller than the duration of glances (10.1 s). This suggests that the experienced drivers in this study not only direct their visual attention more frequently to the different directions and mirrors, but that these glances also tend to be longer in duration as opposed to short, quick glances made by the novice drivers.

The gaze location, frequency and duration for left-turn manoeuvres are displayed in Figure 4-32.

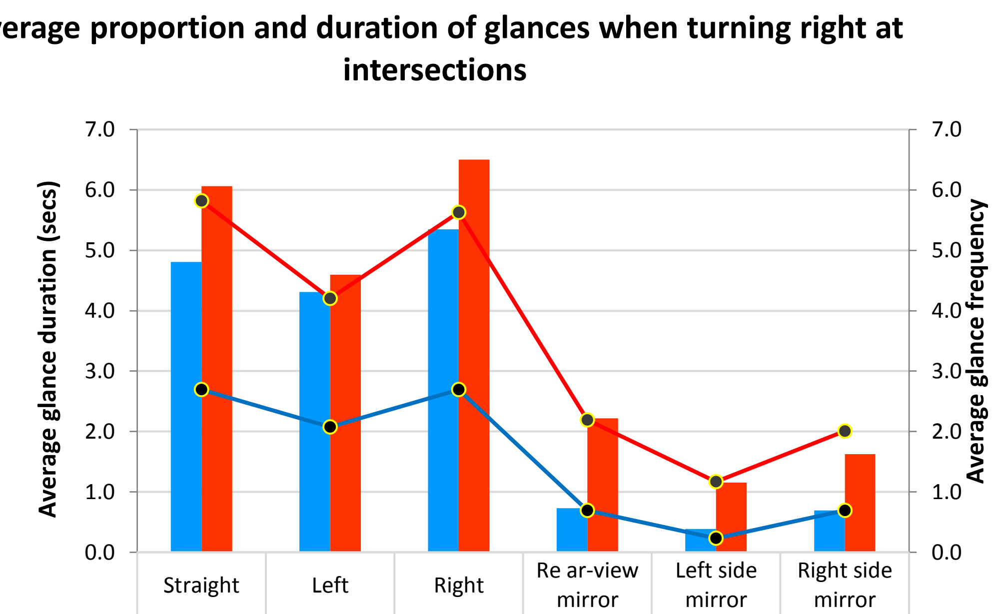


	Straight	Left	Right	Re ar-view mirror	Left side mirror	Right side mirror
Average duration for ND	4.2	3.5	2.8	0.9	0.5	0.0
Average duration for ED	6.2	4.4	5.7	1.9	1.5	1.2
Average frequency for ED	2.7	2.2	2.0	1.5	1.1	0.9
Average frequency for ND	2.8	2.3	1.8	0.9	0.7	0.0

Figure 4-32: Average proportion and duration of glances when turning left at intersections

Compared to straight through manoeuvres, average glance frequency and glance duration for left turn manoeuvres increased for both the novice drivers (increase of 1.8 for average glance frequency and 5 s for average glance duration) and the experienced drivers (increase of 2 for average glance frequency and 10.6 s for average glance duration). For left turn driving manoeuvres, the novice drivers predominantly allocate their attention straight (35%) and in the left (30%) direction. Overall, for the novice drivers the mirror-checking was higher for left turn manoeuvres compared to straight through driving manoeuvres (increased by 0.5 for average glance frequency and 0.7 s for average glance duration). Unlike the trend observed for straight through manoeuvres, the duration of glances (12.0 s) is slightly higher than the average frequency of glances (8.5) for left-turn driving manoeuvres. The graph and table attached to the graph shows that generally the duration of glances is higher than the proportion of glances. The opposite trend was observed for straight through manoeuvres. This suggests that the novice drivers in this study tend to spend slightly more time fixating in the glance directions when performing left turn manoeuvres.

For the experienced drivers, similar to the novice drivers visual attention for left turn driving manoeuvres was mostly allocated to the straight (26%) and left (21%) direction. Overall, for the experienced drivers the mirror-checking was higher for left turn manoeuvres compared to straight through driving manoeuvres (increased by 0.3 for average glance frequency and 1.2 s for average glance duration). In terms of mirror-checking for left turn manoeuvres, the experienced drivers allocated substantially more attention to the mirrors (average glance frequency= 3.5 and average glance duration= 4.6 s) compared to the novice drivers (glance frequency= 1.6 and glance duration= 1.4 s). The graph and table attached to the graph shows that the average duration of glances is consistently higher than the proportion of glances. This suggests that the experienced drivers in this study tend to spend significantly more time fixating in the glance directions when performing left turn manoeuvres. The gaze location, frequency and duration for right-turn manoeuvres are displayed in Figure 4-33.



	Straight	Left	Right	Re ar-view mirror	Left side mirror	Right side mirror
Average duration for ND	4.8	4.3	5.3	0.7	0.4	0.7
Average duration for ED	6.1	4.6	6.5	2.2	1.2	1.6
Average frequency for ED	3.1	2.1	2.9	1.5	0.9	1.3
Average frequency for ND	2.7	2.1	2.7	0.7	0.2	0.7

Figure 4-33: Average proportion and duration of glances when turning right at intersections

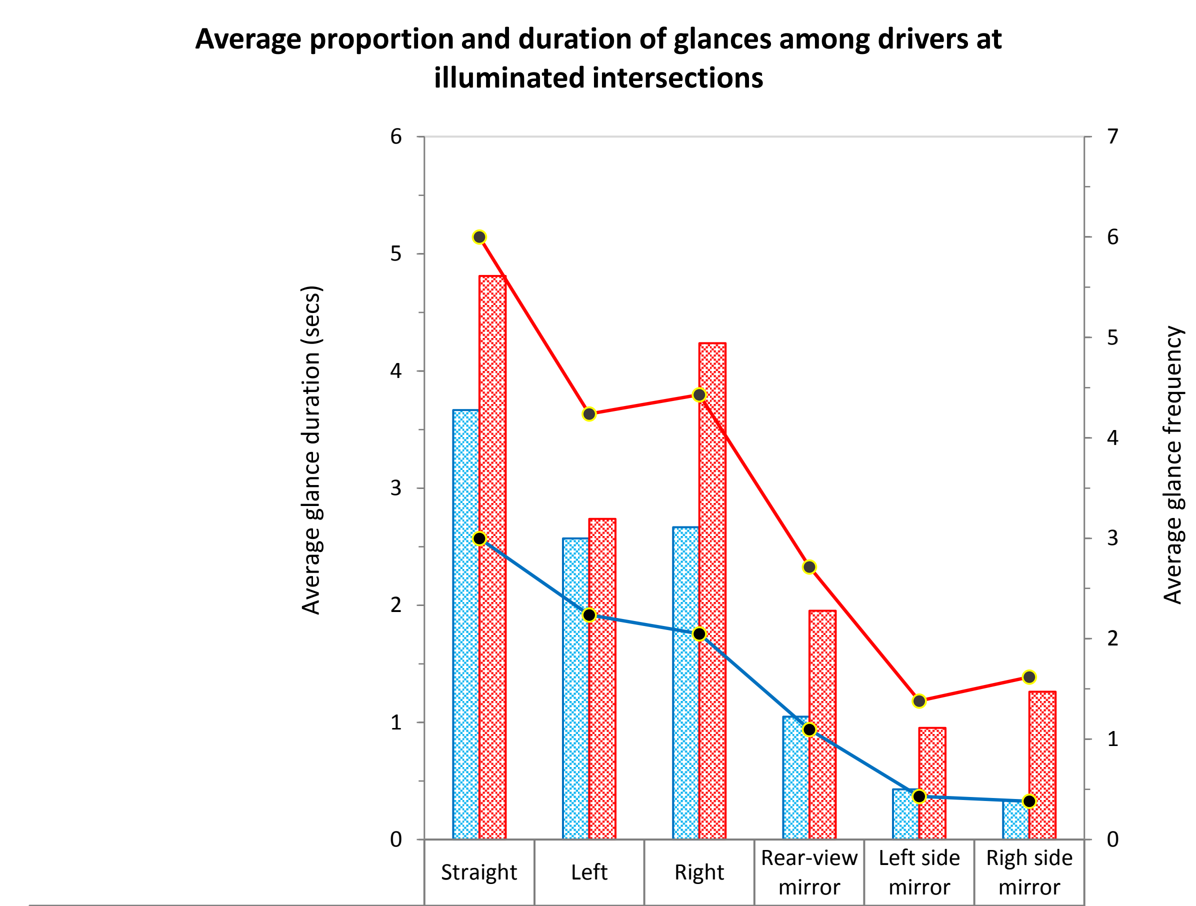
Compared to straight through and left turn driving manoeuvres, average glance frequency and glance duration for right turn manoeuvres was the highest for both the novice drivers (9.1 for average glance frequency and 16.3 s for average glance duration) and the experienced drivers (11.9 for average glance frequency and 22.2 s for average glance duration).

For the right turn driving manoeuvres, the novice drivers predominantly allocate their attention to the right (33%) and straight (30%) directions. Overall, for the novice drivers the mirror-checking in terms of average glance frequency was higher compared to the straight manoeuvres (1.6 vs 1.1) but the same for left turn manoeuvres (1.6 vs 1.6). However, in terms of average glance duration, mirror-checking for right turn manoeuvres (1.8) was higher than left turn manoeuvres (1.4) and straight through manoeuvres (0.7). Similar to trends observed for left turn manoeuvres, the duration of glances (16.3 s) is higher than the frequency of glances (9.1) for right-turn driving manoeuvres, although this difference is greater. The graph and table attached to the graph shows that generally the duration of glances is much higher than the proportion of glances for all scan directions. This suggests that the novice drivers in this study tend to spend slightly more time fixating in the glance directions when performing right turn manoeuvres.

For the experienced drivers, similar to the novice drivers visual attention for right turn driving manoeuvres was mostly allocated in the right (29%) and straight (27%) direction. terms of mirror-checking for right turn manoeuvres, the experienced drivers allocated substantially more attention to the mirrors (average glance frequency= 3.7 and average glance duration= 5 s) compared to the novice drivers (average glance frequency= 1.6 and average glance duration= 1.8 s). The graph and table attached to the graph also shows that the average duration of glances is consistently and substantially higher than the average frequency of glances for all scan directions. This suggests that the experienced drivers in this study tend to spend significantly more time fixating in the glance directions when performing right turn manoeuvres.

4.3.4.3 Gaze behaviour at intersections under different lighting conditions

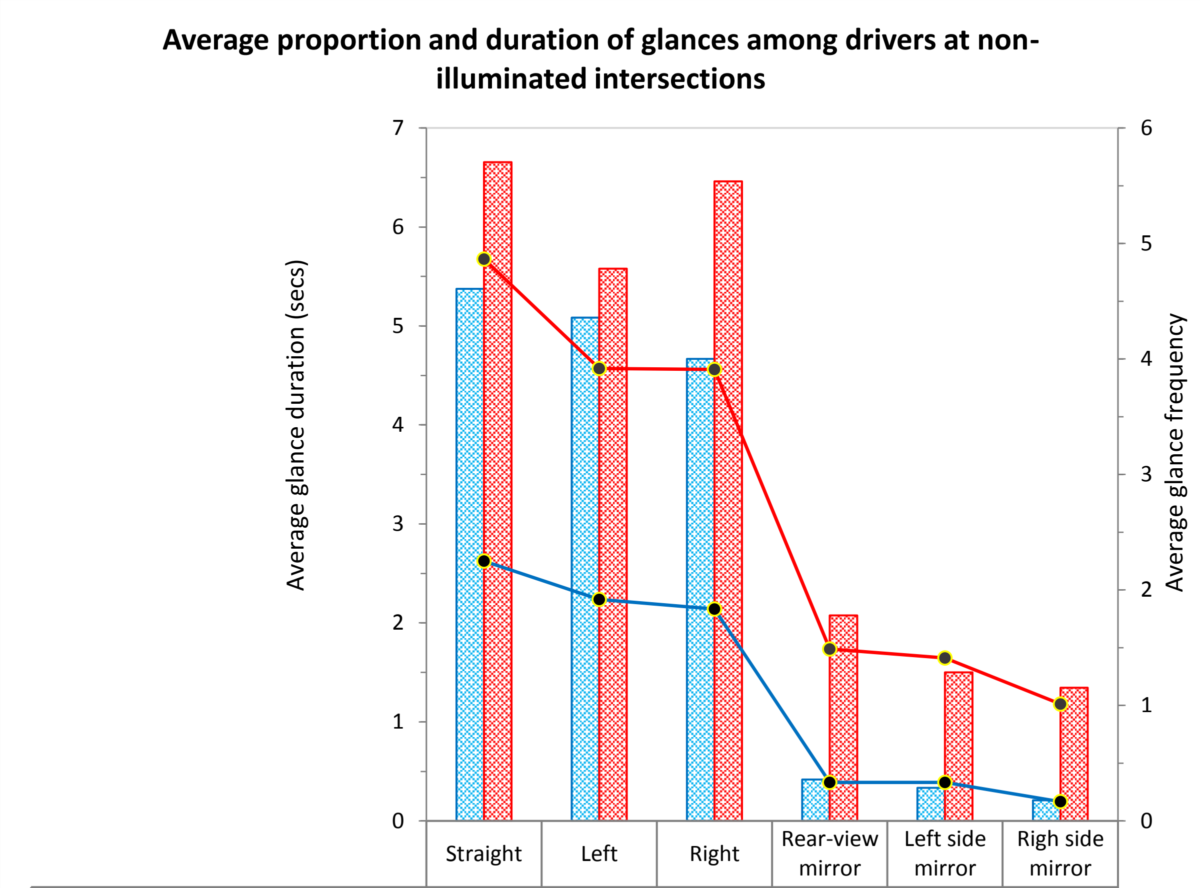
Gaze behaviour at illuminated and non-illuminated intersections was analysed for the novice and the experienced drivers. In total, for the novice drivers gaze behaviour was examined at 12 illuminated intersections and 12 non-illuminated intersections. For the experienced drivers, gaze behaviour was examined at 12 illuminated intersection and 13 non-illuminated intersections. The data is displayed according to illumination condition and not driving manoeuvre (straight, right or left). At each intersection and for each driving manoeuvre, the glance frequency (number of times the drivers looked in a particular direction such as left, right, left mirror, right mirror, straight ahead, and rear-view mirror) and glance duration (the time spent scanning a particular direction) was recorded. Glance duration was recorded from the time the driver directed their gaze/ head in one direction and ended when the driver shifted their gaze/head in another direction. The results for gaze behaviour at illuminated intersections are shown in Figure 4-34 and the results for gaze behaviour at non-illuminated intersections are shown in Figure 4-35.



	Straight	Left	Right	Rear-view mirror	Left side mirror	Righ side mirror
Average glance duration for ND	3.7	2.6	2.7	1.0	0.4	0.3
Average glance duration for ED	4.8	2.7	4.2	2.0	1.0	1.3
Average glance frequency for ED	3.0	2.0	2.4	1.6	1.0	1.2
Average glance frequency for ND	3.0	2.2	2.0	1.1	0.4	0.4

Figure 4-34: Average proportion and duration of glances among drivers at illuminated intersections

According to the results displayed in Figure 4-34 and Figure 4-35, the average glance frequency and average glance duration changes as the lighting at intersections vary. For the novice drivers, the average glance frequency is higher at illuminated intersections (9.1) but lower at non-illuminated intersection (6.8). However, the average glance duration is lower at illuminated intersections (10.7 s) but higher at non-illuminated intersection (16.1). The same trend is observed for the experienced drivers. The average glance frequency is higher at illuminated intersections (11.2) but lower at non-illuminated intersection (9.8). However, the average glance duration is lower at illuminated intersections (16.0 s) but higher at non-illuminated intersection (23.7 s). These results indicate that at illuminated intersections the novice and the experienced drivers have a higher frequency of glances, but at non-illuminated intersections they have a higher duration of glances. In terms of mirror-checking, all drivers demonstrated a general decrease in checking the mirrors from illuminated to non-illuminated intersections. At illuminated intersections, the average glance frequency and average glance duration was higher for the experienced drivers (11.2 and 16.0s, respectively) compared to the novice drivers (9.1 and 10.7s, respectively). At non-illuminated intersections, the average glance frequency and average glance duration was higher for the experienced drivers (9.8 and 23.7 s, respectively) compared to the novice drivers (6.8 and 16.1 s, respectively).



	Straight	Left	Right	Rear-view mirror	Left side mirror	Righ side mirror
Average glance duration for ND	5.4	5.1	4.7	0.4	0.3	0.2
Average glance duration for ED	6.7	5.6	6.5	2.1	1.5	1.3
Average glance frequency for ED	2.6	2.0	2.1	1.2	1.1	0.8
Average glance frequency for ND	2.3	1.9	1.8	0.3	0.3	0.2

Figure 4-35: Average proportion and duration of glances among drivers at non-illuminated intersections

4.3.5 Secondary task engagement at night

4.3.5.1 Frequency of secondary task engagement at night time

The frequency of secondary task engagement while driving at night is displayed in Figure 4-36. The driver distractions at night with the highest frequency for novice drivers were mobile phone use (9), conversing with a passenger (7) and eating/drinking (7). The driver distractions at night with the highest frequency for experienced drivers were conversing with a passenger (8), mobile phone use (6) and smoking (7).

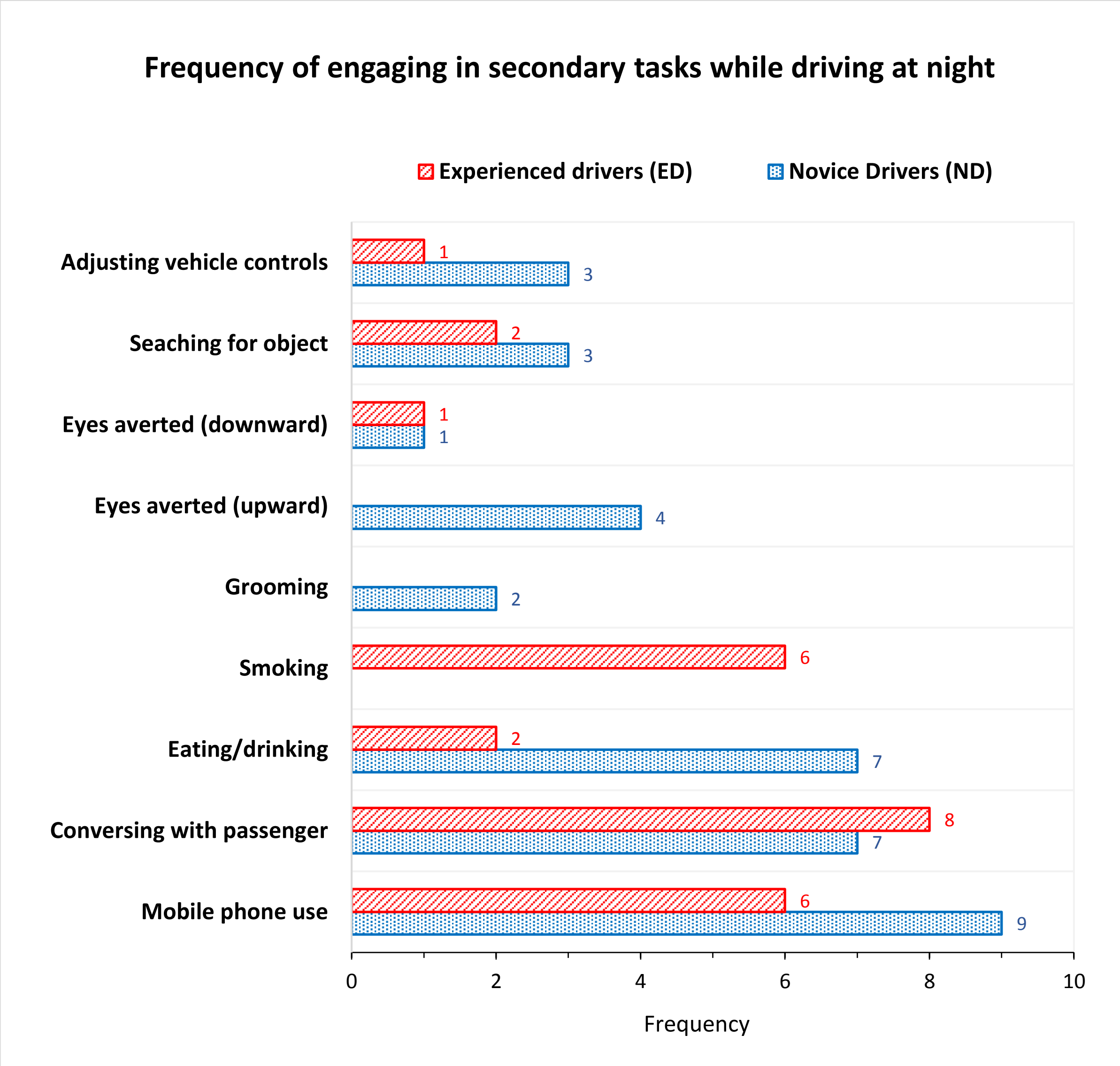


Figure 4-36: Frequency of engaging in secondary tasks while driving at night

4.3.5.2 Frequency of secondary task engagement at day and night time

The frequency of driver distractions at night time was also compared to driver distractions during daytime. Data on secondary task engagement during daylight conditions was retrieved from Venter (2014) and compared to the driver distractions observed at night time in this study. Driver distraction data was available for all distraction types except ‘conversing with passenger’, ‘eyes averted (upward)’ and ‘adjusting vehicle controls’. The results are shown in Figure 4-37.

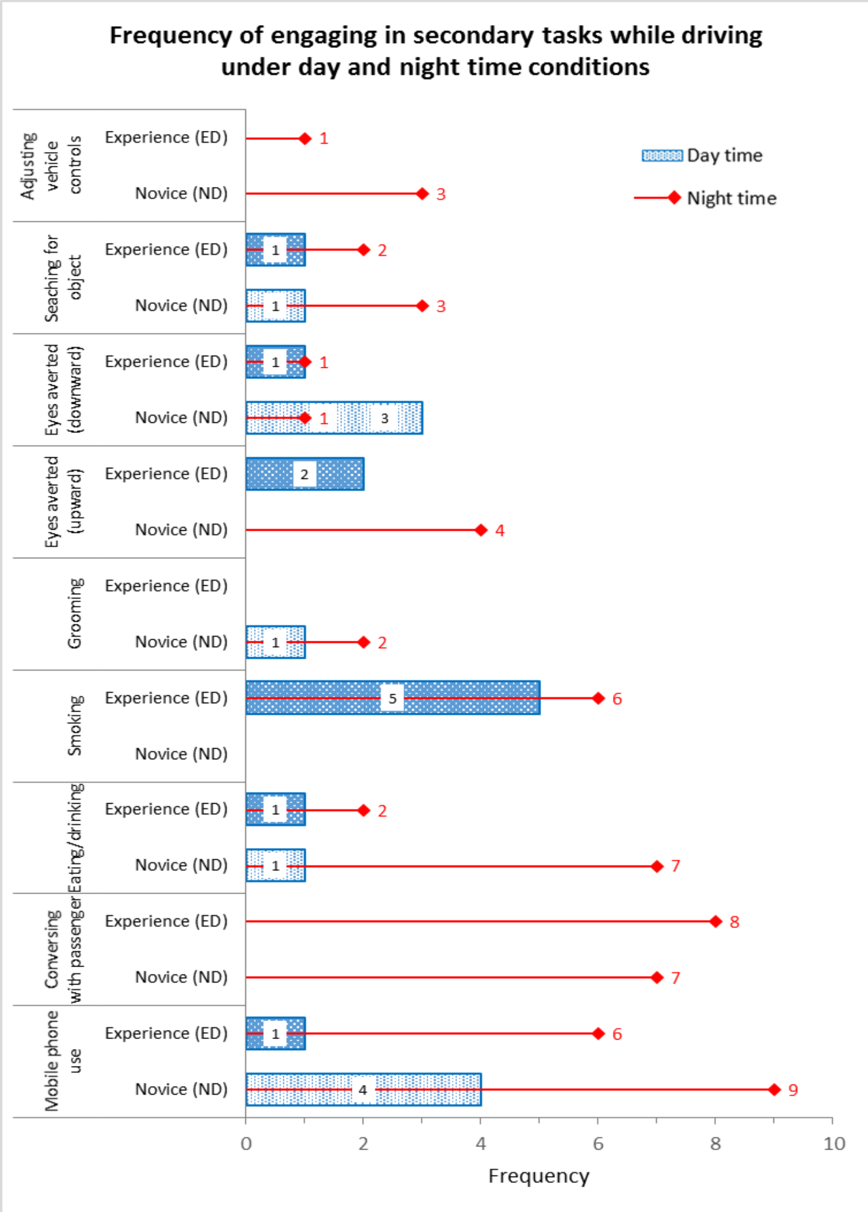


Figure 4-37: Frequency of engaging in secondary tasks while driving under day and night time conditions

Overall, the number of distractions occurring at night (36) is almost four times higher than the number of distractions occurring during the day (10). Novice drivers demonstrated the greatest increase in distractions at night time compared to experienced drivers. The frequency of driver distractions at night time surpasses all distraction types when compared to distractions occurring during daytime conditions (except for ‘eyes averted downward’ among novice drivers).

4.3.5.3 Average speed among drivers while engaging in secondary tasks

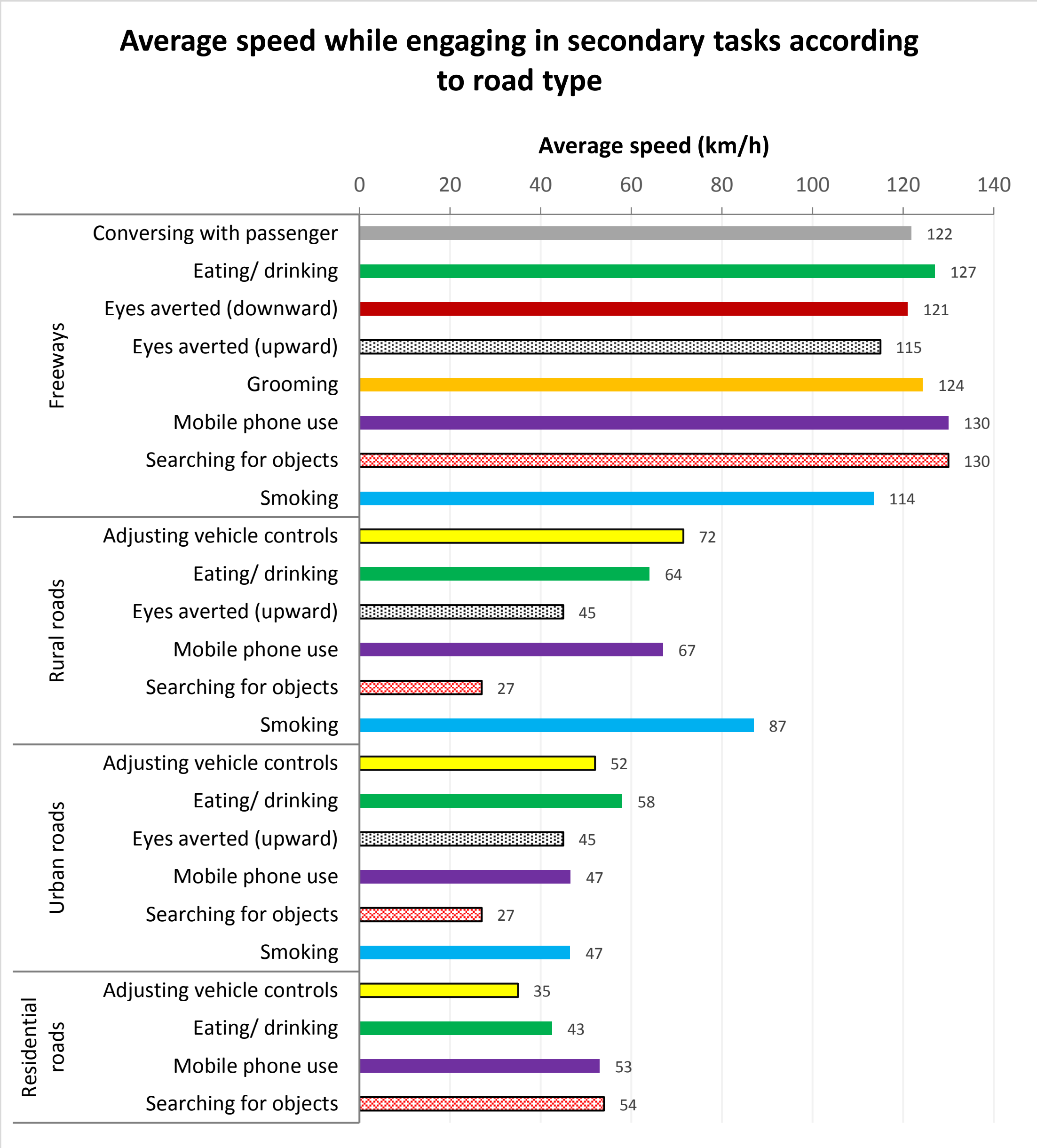


Figure 4-38: Average speed while engaging in secondary tasks at night

The average speed while engaging in secondary tasks at night according to road type for both novice and experienced drivers is displayed in Figure 4-38. The results show that when engaging in secondary tasks, average speed is relatively high on freeways. Moreover, for most driver distractions, drivers are violating the speed limit whilst engaging in secondary tasks. On urban roads, the average speed whist engaging in secondary tasks is also high. The driver distractions ‘mobile phone use’ and ‘smoking’ are engaged in at relatively high speeds.

4.3.5.4 Average task duration among drivers while engaging in secondary tasks

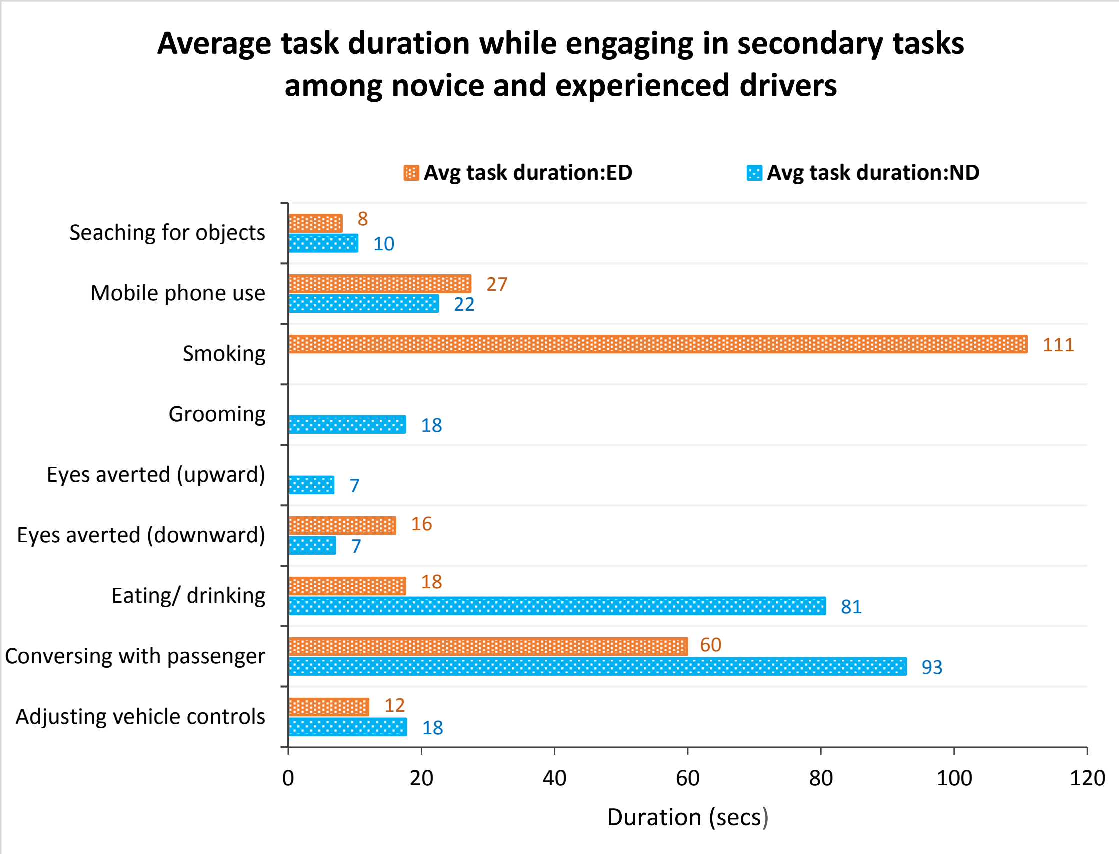


Figure 4-39: Average task duration while engaging in secondary tasks at night

The average duration of secondary tasks while driving at night for both novice and experienced drivers is displayed in Figure 4-39. According to the results, the novice drivers spent a greater amount of time on the following distractions: conversing with passenger (93 s), eating/drinking (81 s) and mobile phone use (22 s). The experienced drivers spent a greater amount of time on the following distractions: smoking (111 s), conversing with passenger (60 s) and mobile phone us (27 s).

4.3.6 Traffic violations at night

The frequency of traffic violations at night are shown in Figure 4-40. The most frequent traffic violation recorded for the novice drivers is mobile phone use (10) and disobeying stop signs (8). Disobeying stop signs was another frequent misdemeanour for novice drivers. The traffic violations with the highest frequency for the experienced drivers are not wearing a seat belt (7) and mobile phone use (6).

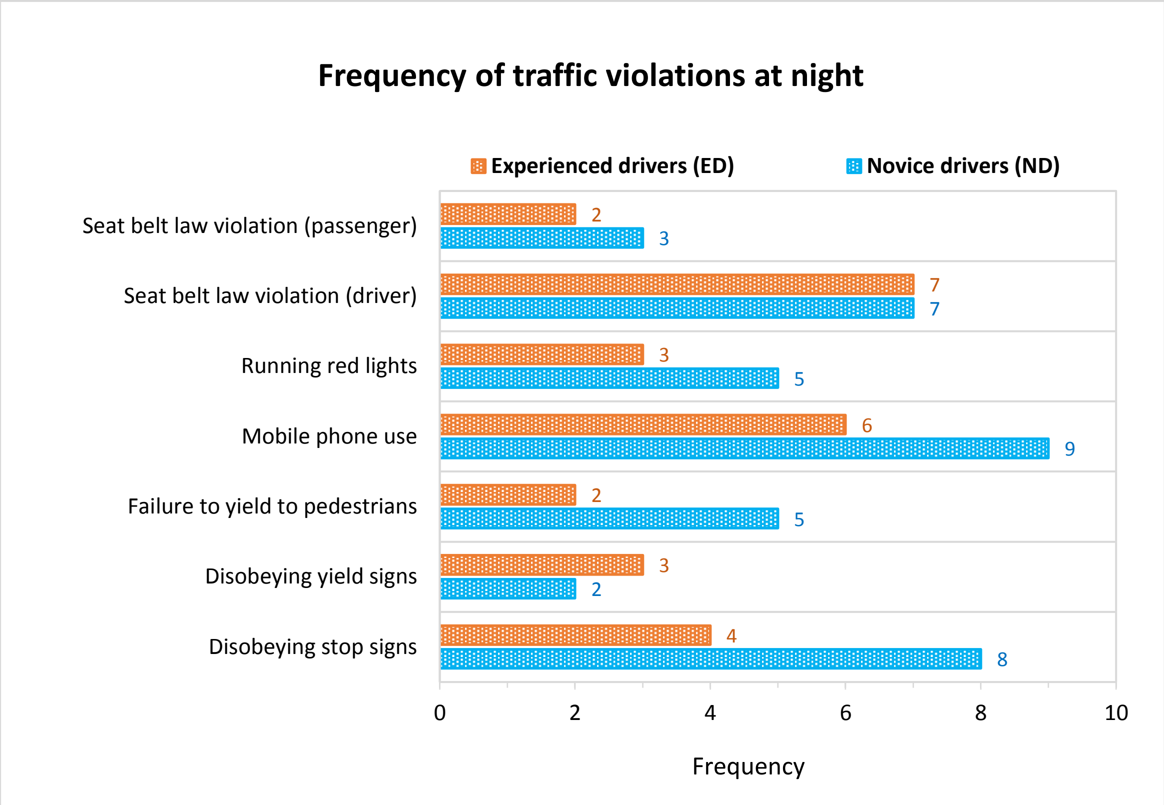


Figure 4-40: Frequency of traffic violations at night

4.4 Analysis of Night Time Surveys

This section presents the findings from the night driving surveys used in this study. The total number of survey respondents was 177. The graphs in the next sections provide the demographic data of survey respondents and the results obtained for the various survey questions.

4.4.1 Survey respondent demographics

In total, 177 participants completed the night driving survey. Figure 4-41 shows the distribution of survey respondents according to gender. The proportion of male respondents (53%, n= 94) was slightly higher than the proportion of female respondents (47%, n= 83).

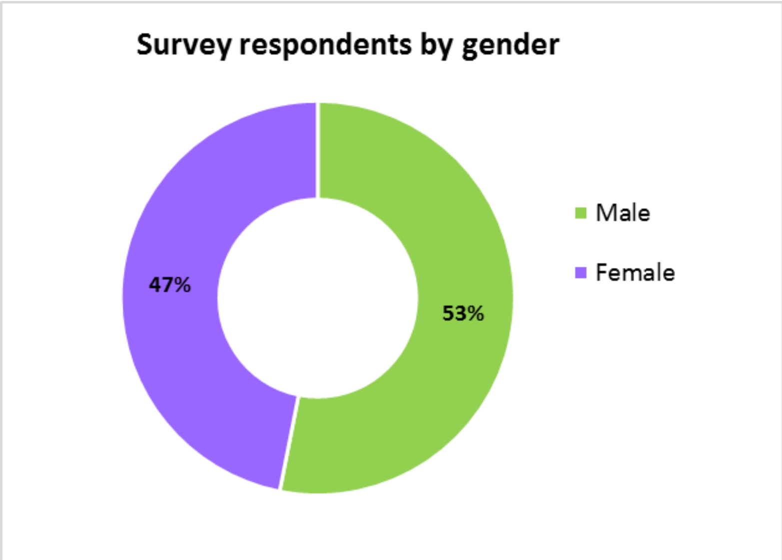


Figure 4-41: Survey respondents by gender

In terms of driver age, Figure 4-42 shows middle-aged drivers (40%, n= 71) comprised the majority of survey respondents followed by young drivers (37%, n= 65) and elderly drivers (23%, n= 41).

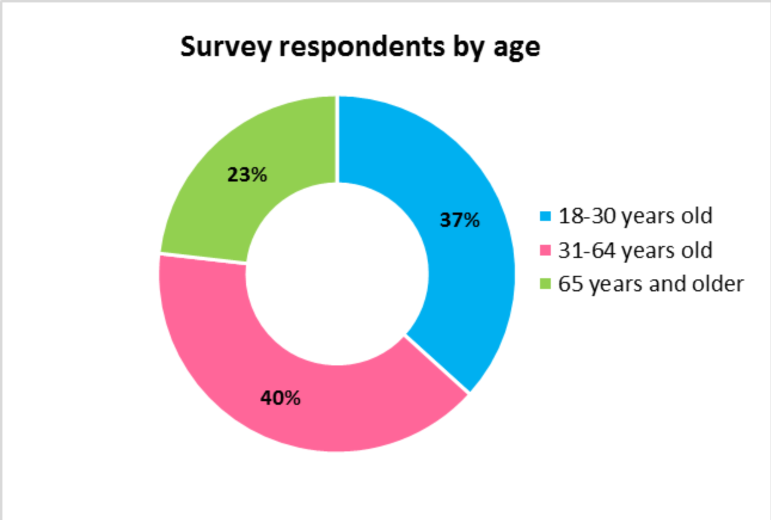


Figure 4-42: Survey respondents by age

Survey responses were also analysed according to driving experience. Most survey respondents had been driving for 10-20 years. Respondents were also categorised according to novice driver (0-18 months of driving experience) or experienced driver (1.5-more than 20 years of driving experience). According to Figure 4-43, novice drivers constituted 18% of survey respondents (n= 32) while experienced drivers constituted 82% of survey respondents (n= 145).

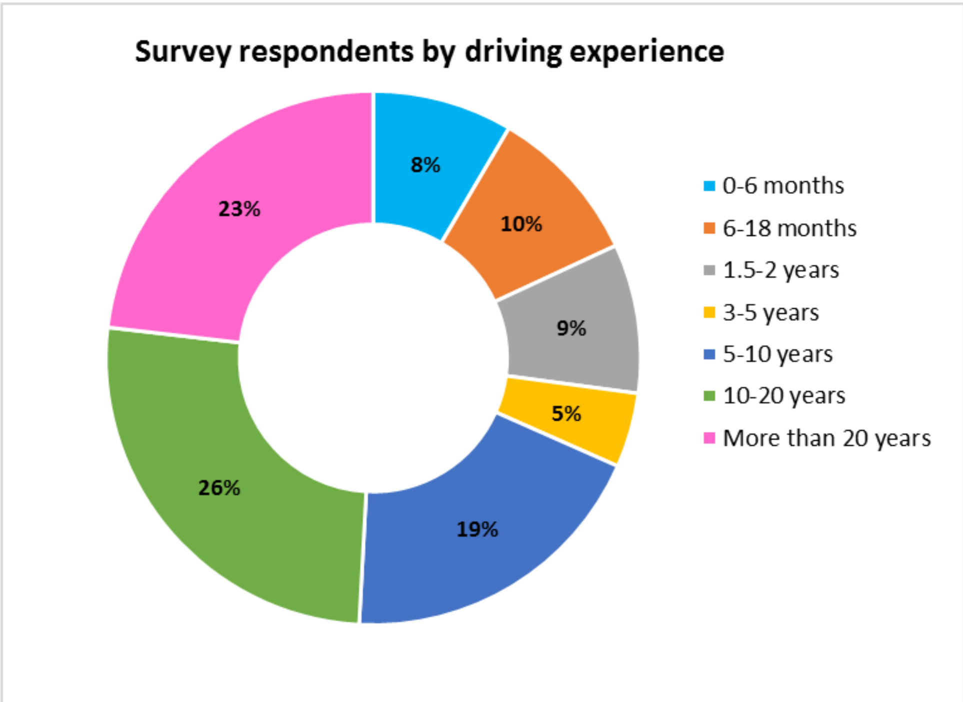


Figure 4-43: Survey respondents by driving experience

4.4.2 Perceptions of night driving

4.4.2.1 Driving enjoyment at night

Figure 4-44 displays data on drivers' level of enjoyment of night driving.

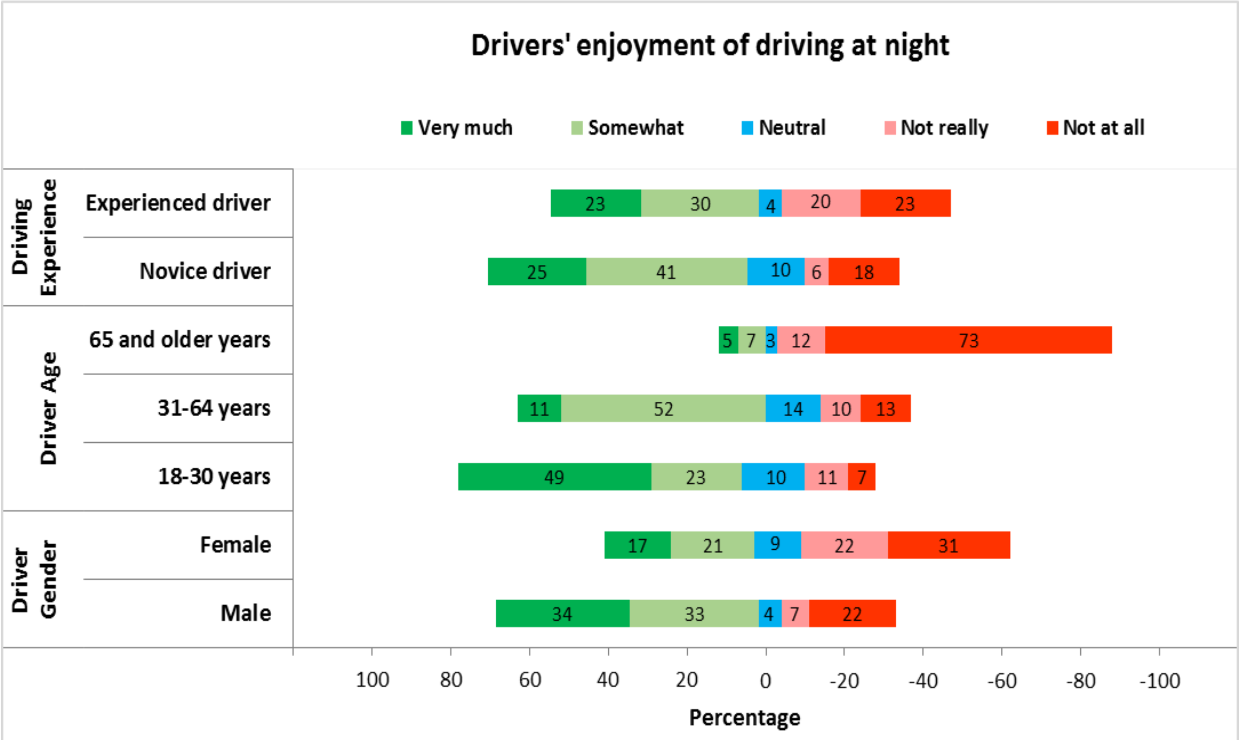


Figure 4-44: Drivers' enjoyment of driving at night

In terms of age, more young drivers (72%) indicated that they enjoy driving at night very much or to some extent, followed by middle-age drivers (63%) and elderly drivers (12%). Elderly drivers (85%) reported the lowest level of driving enjoyment at night, with 12% of respondents indicating that they do not really enjoy it and 73% of respondents indicating that they do not enjoy it at all. Male drivers (67%) showed significantly higher levels of driving enjoyment at night compared to their female counterparts (38%). In terms of driving experience, novice drivers (66%) showed slightly higher levels of driving enjoyment at night compared to experienced drivers (53%). Overall, young drivers, males and novice drivers reported higher levels of driving enjoyment at night, respectively.

4.4.2.2 Ability to drive safely at night

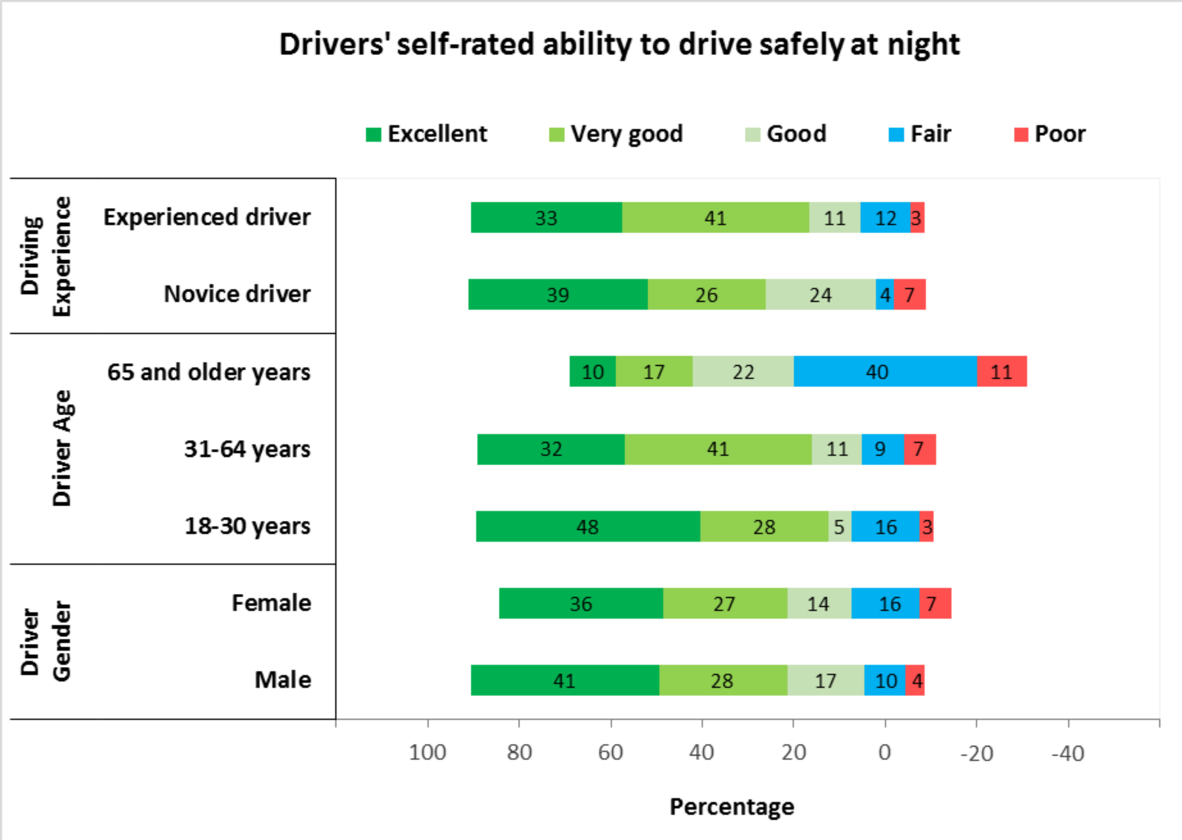


Figure 4-45: Drivers' self-rated ability to drive safely at night

Figure 4-45 displays data on drivers' ability to drive safely at night. More young drivers (76%) rated their driving ability at night positively (excellent or very good), followed by middle-age drivers (73%) and elderly drivers (27%). The majority of elderly drivers (51%) rated their ability to drive safely at night more negatively (fair or poor). In terms of gender, male drivers (69%) reported slightly higher positive ratings of their driving ability at night when compared with female drivers (63%). Experienced drivers (74%) rated their ability to drive safely at night more positively than novice drivers (65%). Overall, there was a tendency to rate driving ability at night more positively among all driver groups except elderly drivers. From each driver sub-group, young drivers, experienced drivers and male drivers rated their ability to drive safely at night more highly.

4.4.2.3 Concern about having an accident at day and night time

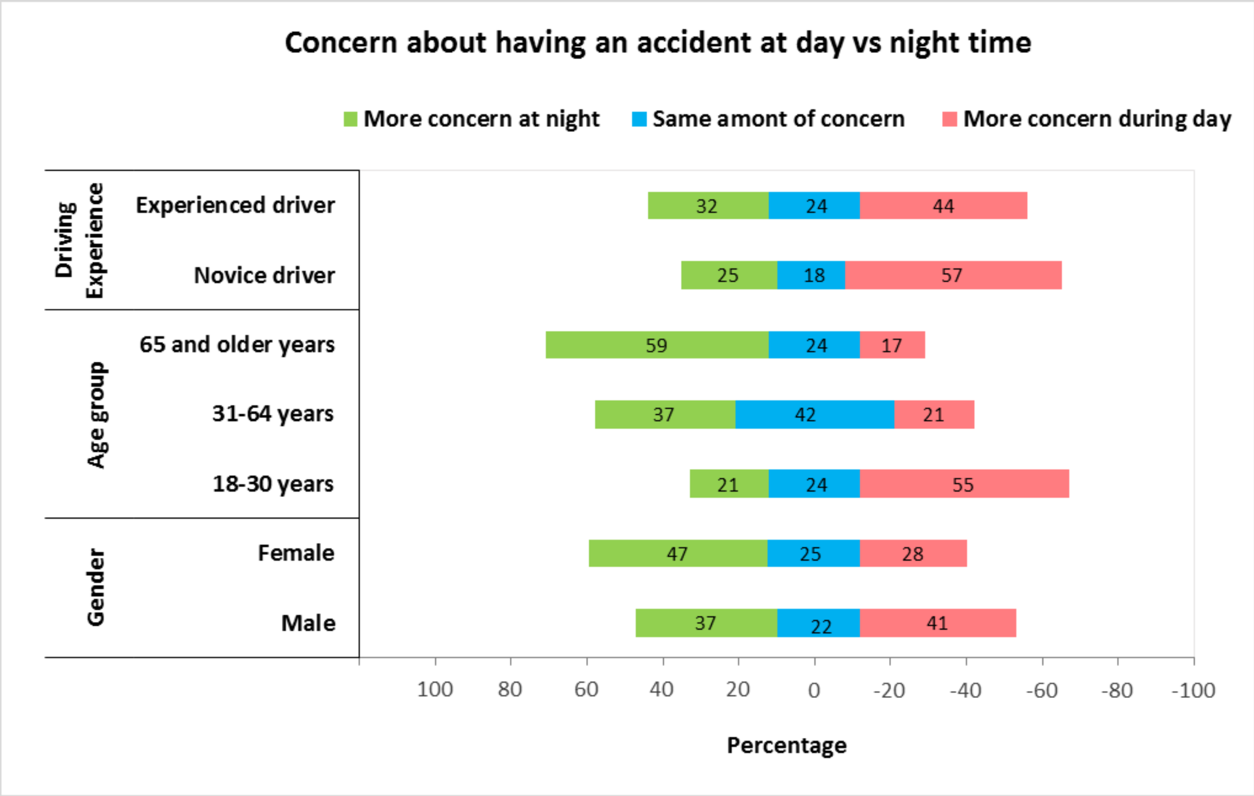


Figure 4-46: Concern about having an accident at day vs night time

To investigate crash risk perception at day and night time, drivers were asked about their level of accident concern at night compared to daytime. The answer categories ‘more concern at night’ was interpreted as higher risk perception at night, ‘same amount of concern’ was interpreted as moderate risk perception at night and ‘more concern during the day’ was interpreted as lower risk perception at night. The results are shown in Figure 4-46.

In general, most drivers showed were more concerned about being involved in a crash during daytime than night time. In terms of age, elderly drivers (59%) showed the most concern of being involved in a crash at night time, followed by middle-age drivers (37%) and young drivers (21%). A greater disparity was found between the proportion of accident concern at night for male and female drivers’, with the 47% of females and 37% of males indicating that they have more concern about being involved in a crash at night time. Novice and experienced drivers also showed similarities in accident concern at day and night time but novice drivers (25%) had less concern about having an accident at night compared to experienced drivers (32%). Overall, elderly drivers demonstrated higher risk awareness at night while novice drivers and young drivers demonstrated lower risk perception at night time.

The reasons for drivers' crash concerns at night time were also investigated to determine the underlying risk perception of night driving. Drivers' were asked to rank a list of 10 crash concerns at night time from 1-10, with 1 being the most important and 10 being the least important accident concerns at night time. The results for young, middle-age and elderly drivers are displayed in Table 4-14.

Table 4-14: Drivers' accident concerns at night ranked from 1-10

Rank	Young	Middle-age	Elderly
1	Other reckless or drunk drivers	Lack of visibility due to low lighting	Difficulty seeing because of eye-sight related problems
2	Being a victim of crime	Other reckless or drunk drivers	Lack of visibility due to low lighting
3	Not seeing unexpected hazards such as dangerous objects	Not seeing unexpected hazards such as dangerous objects	Other reckless or drunk drivers
4	Not getting help if I had an accident	Being a victim of crime	Not seeing unexpected hazards such as dangerous objects
5	Lack of visibility due to low lighting	Difficulty seeing because of eye-sight related problems	Being a victim of crime
6	Not seeing unexpected pedestrians	Not getting help if I had an accident	Not seeing unexpected pedestrians
7	Difficulty seeing because of eye-sight related problems	Not seeing unexpected pedestrians	Not getting help if I had an accident
8	Not seeing road signs, traffic lights and road markings	Not seeing road signs, traffic lights and road markings	Lack of visibility due to adverse weather conditions
9	Lack of visibility due to adverse weather conditions	Lack of visibility due to adverse weather conditions	Not seeing road signs, traffic lights and road markings
10	Not seeing animals	Not seeing animals	Not seeing animals

According to the results, the top three accident concerns at night time for young drivers are 'other reckless and drunk drivers', 'being a victim of crime' and 'not seeing unexpected hazards such as dangerous objects'. Middle-age drivers' accident concerns were primarily attributed to ‘lack of visibility due to low lighting’, ‘other reckless or drunk drivers’ and ‘not seeing unexpected hazards’. Elderly drivers’ concern about having an accident at night time were mainly due to ‘difficulty seeing because of eye-sight related problems’, ‘lack of visibility due to low lighting’ and ‘other reckless or drunk drivers’.

Interestingly, visibility-related concerns featured primarily among middle-age and elderly drivers. Young drivers’ rated poor visibility due to low lighting much lower on the list (rank 5) compared to middle-age (1) and elderly drivers (2). Overall, for all drivers external factors that threaten safety such as ‘other reckless or drunk drivers’, ‘being a victim of crime’ and ‘not getting help if had an accident’ were generally more important concerns than issues related to visibility (not seeing pedestrians, not seeing traffic lights and road signs, etc.). However, all drivers showed a greater tendency to ranking ‘not seeing unexpected hazards such as dangerous objects’ higher, it was ranked number 3 for young and middle-age drivers and number 4 for elderly drivers. This indicates that in terms of visibility issues experienced at night, drivers may experience greater difficulty in seeing unexpected hazards and dangerous objects.

4.4.3 Comparison of driving behaviour at day and night time

4.4.3.1 All drivers

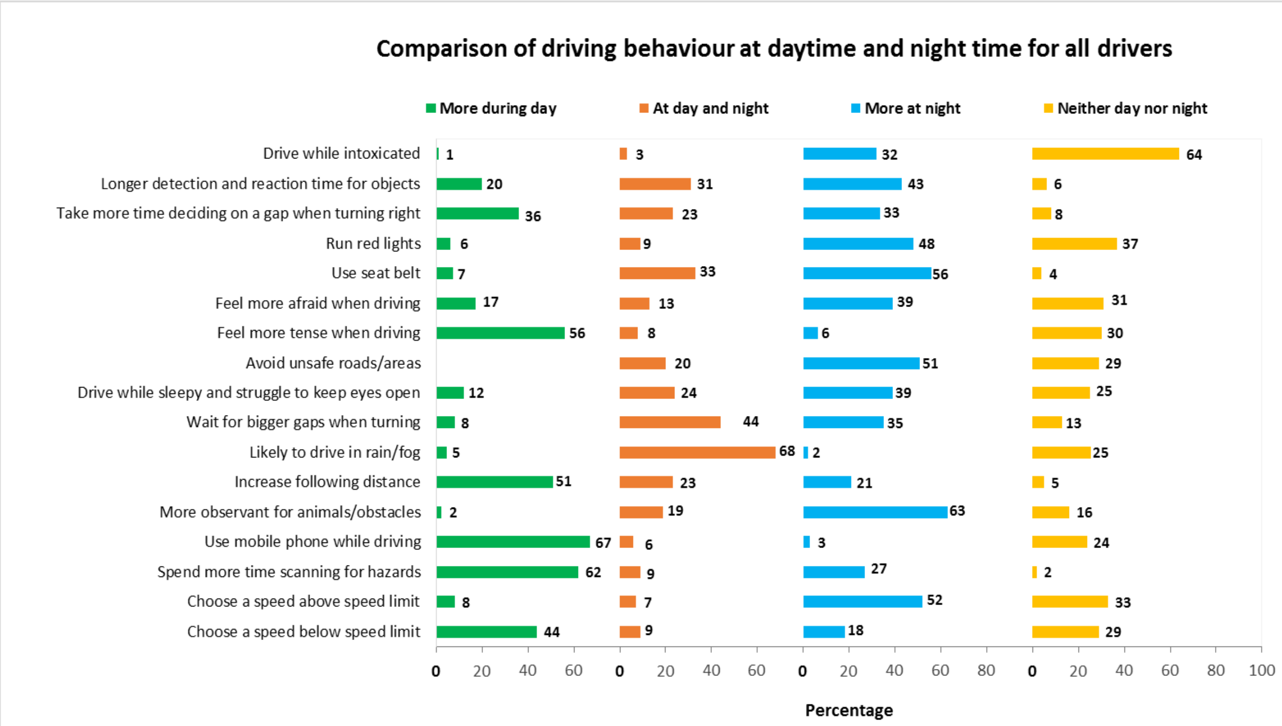


Figure 4-47: Comparison of driving behaviour at day and night time (all drivers)

Drivers were asked to rate the frequency of engaging in various behaviours and actions when driving at night relative to daytime. The results for all drivers are shown in Figure 4-47. In terms of drink driving, 32% of drivers revealed that they have driven at night when they think they may have exceeded the legal blood-alcohol limit. Most drivers indicated that it takes them longer to see and react to objects in the road environment during night time compared to daytime (43% vs 20% of drivers). Red light running was more prevalent at night time; with 48% of drivers admitting that they intentionally entered an intersection after the traffic light has turned red more frequently at night. Seat belts were also more frequently used at night time (56%) compared to daytime (7%) or during both day and night time conditions (33%). While the majority of drivers (39%) feel more afraid when driving at night, a greater proportion of drivers indicated that they feel tenser while driving during daytime (56% of drivers). Only 6% of drivers indicated that they feel tenser while driving at night time. Car following distance was increased more frequently during daytime compared to night time (51% vs 21% of drivers).

Distractions such as mobile phone use was more prevalent among drivers during daytime (67%) compared to night time (3%). A higher proportion of drivers indicated that they spent more time scanning for hazards during daytime conditions (62%) compared to night time (27%). In terms of speed choice, higher speeds were mainly chosen at night time (52% of drivers) while lower speeds were mainly chosen during daytime (44%).

4.4.4 Speeding behaviour

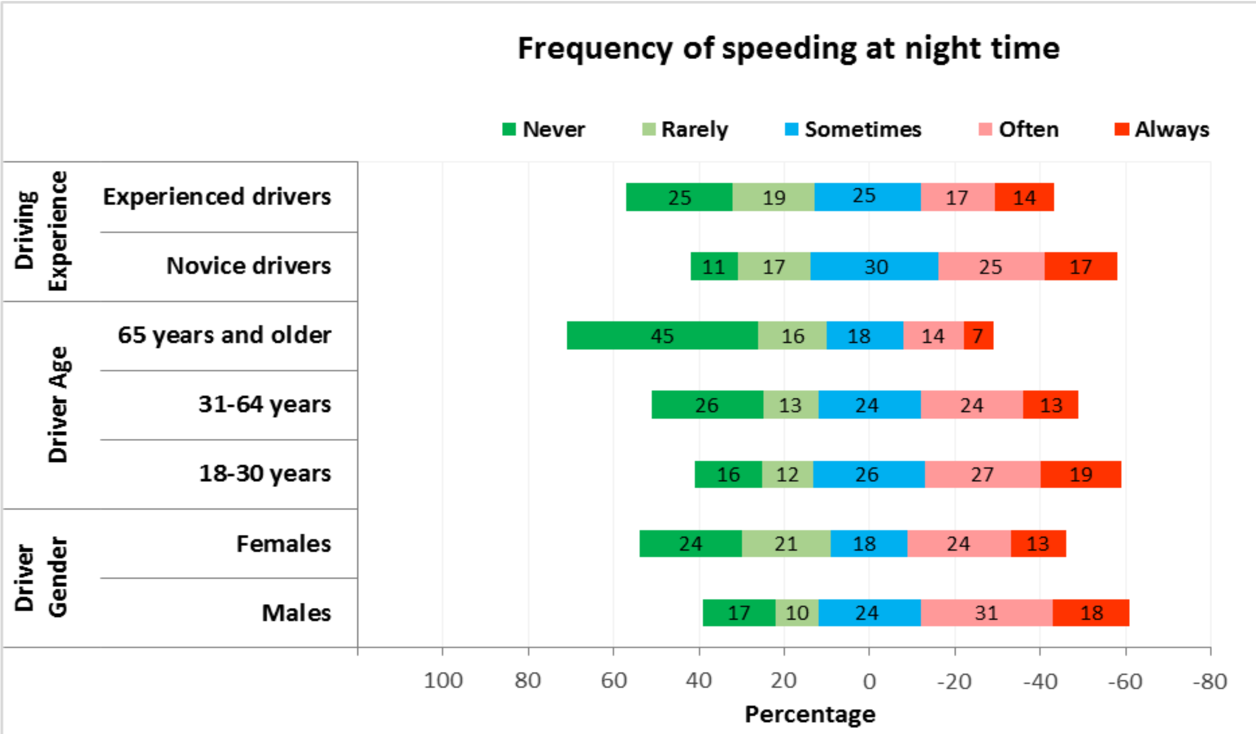


Figure 4-48: Frequency of speeding at night time

The frequency of speeding at night was investigated and the results are displayed in Figure 4-48. In terms of age, young drivers (46%) engaged in speeding more frequently (often or always) at night time, followed by middle-age drivers (37%) and elderly drivers (21%). Elderly drivers demonstrated the lowest speed propensity at night, with 61% of respondents indicating that they never or rarely speed at night. Male drivers (49%) showed significantly higher levels of speeding at night compared to their female counterparts (37%). In terms of driving experience, novice drivers (42%) showed slightly higher levels of speeding compared to experienced drivers (31%). Overall, young drivers, males and novice drivers demonstrated higher frequency of speeding at night, respectively. Conversely, elderly drivers, experienced drivers and female drivers demonstrated the lowest frequency of speeding at night, respectively.

4.4.4.1 Motivations for speeding

To understand the reasons that motivate speeding at night, drivers' were asked to indicate to which extent the reasons listed in Figure 4-49 influences their decision or would be influential in their decision to speed at night. Drivers' responses were assessed on a five-point scale. However, to simplify data analysis, the responses were condensed into three categories, where positive responses represent 'extremely likely' and 'likely' responses, neutral responses represent 'neither likely nor unlikely' responses and negative responses represent 'extremely unlikely' and 'unlikely' responses.

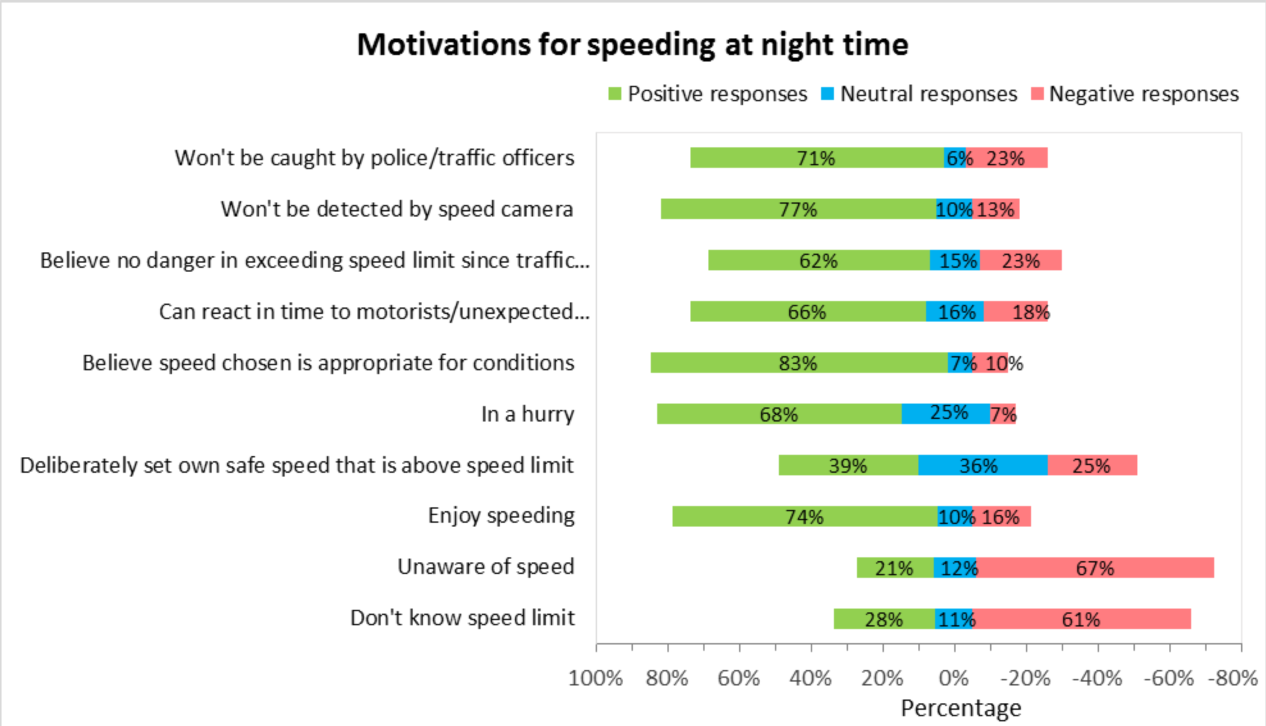


Figure 4-49: Motivations for speeding at night time

According to the results, the primary motivation for speeding at night is due to low perceived risk associated with speeding. A significant proportion of drivers indicated that they are likely to speed at night if they thought they would not be detected by speed cameras (77%) and if they thought they would not be caught by police/traffic officers (71% of drivers). A high proportion of drivers (74%) also indicated that they speed at night or would do so because they enjoy speeding. Self-efficacy was also a prominent factor in motivations to speed at night. On this point, 62% of drivers indicates that they do or would speed because they believe there is no danger in exceeding the speed limit since traffic is less, 66% of drivers believe they would still be able to react in time to unexpected pedestrians, obstacles and motorists and 83% of drivers believe that the speed selected is still appropriate for the conditions.

4.4.5 Experience of fatigue at night

<u>All drivers</u>

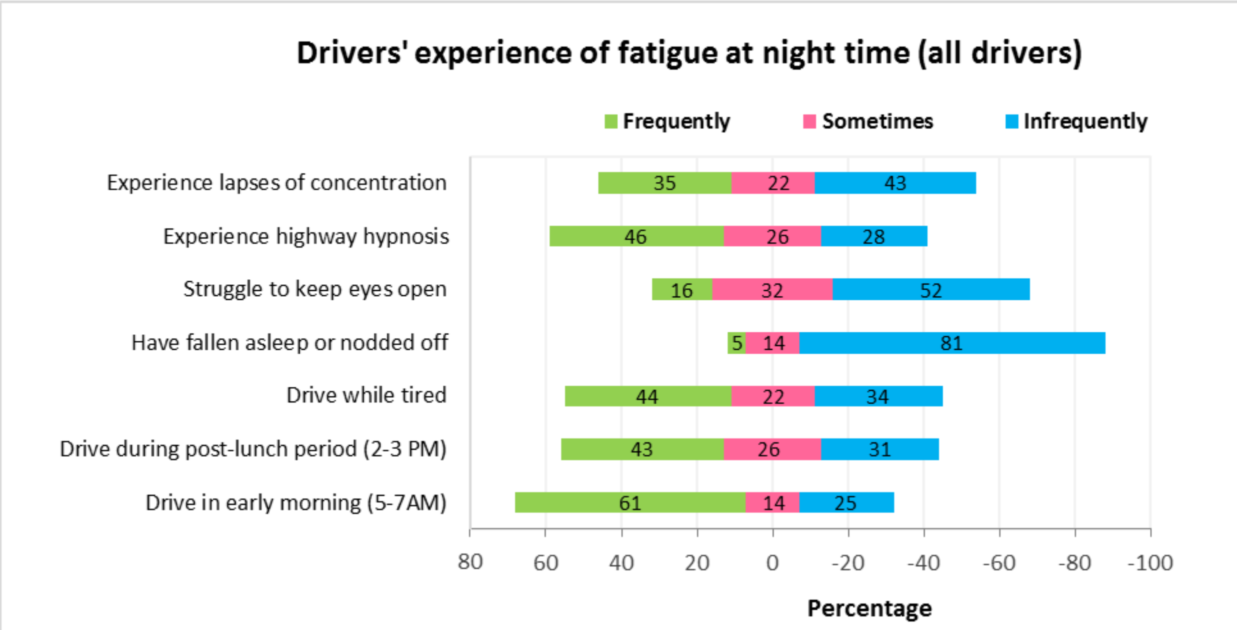


Figure 4-50: Drivers' experience of fatigue at night (all drivers)

Drivers' experience of fatigue at night time was investigated and the results for all drivers are shown in Figure 4-50. A large proportion of drivers (44%) indicated that they frequently drive while tired at night. In terms of driving during time periods when fatigue and sleepiness is known to be higher, 43% of drivers indicated that they frequently drive during the post-lunch period and 61% of drivers indicated that they drive during the early hours of the morning. While a smaller proportion of drivers reported that they frequently struggle to keep their eyes open while driving at night, a higher proportion revealed that they frequently experience highway hypnosis at night (16% vs 46%, respectively). In terms of experiencing lapses in concentration when driving at night, 35% of drivers indicated that this occurs frequently and 22% of drivers indicated that this occurs occasionally.

Driver gender

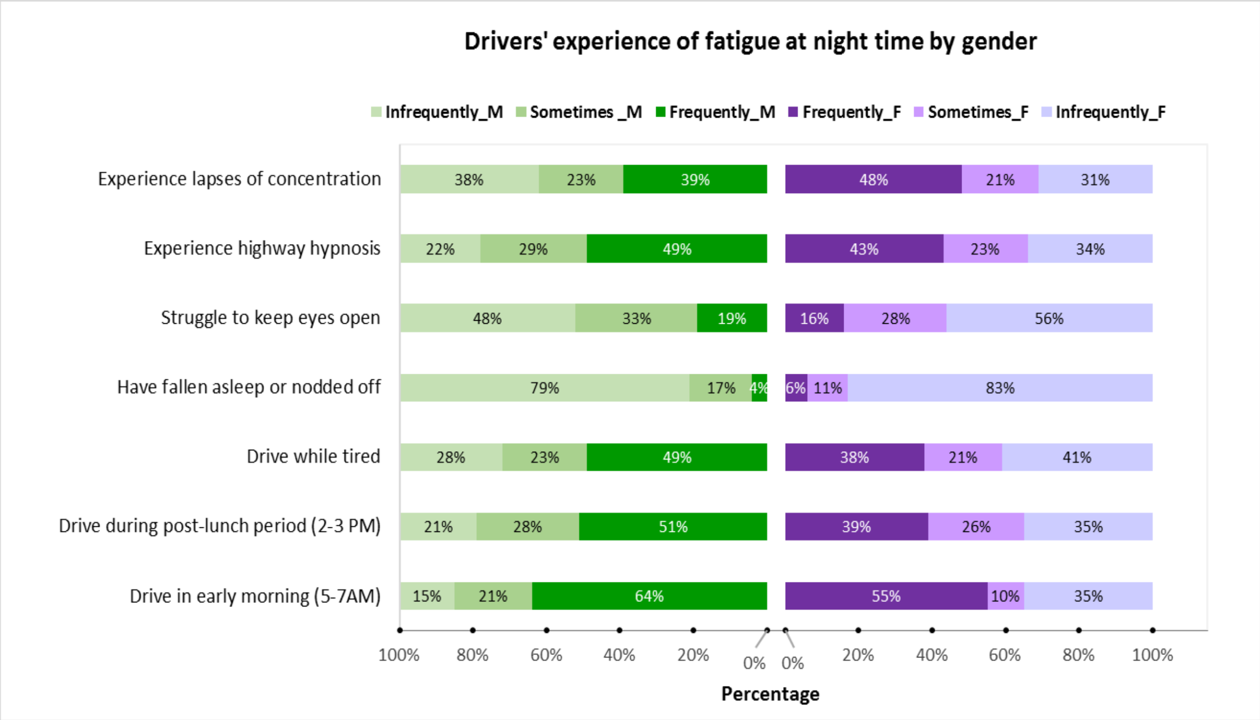


Figure 4-51: Drivers' experience of fatigue at night time by gender

Figure 4-51 presents data on the male and female drivers' experience of fatigue at night time. According to the results, male drivers (49%) drive more frequently while tired at night compared to female drivers (38%). In terms of driving during time periods when fatigue and sleepiness is known to be higher, more male drivers than female drivers demonstrated a higher propensity to drive during the post lunch period (51% vs 39%, respectively) and during the early hours of the morning (64% vs 55%, respectively). Female drivers (6%) were more likely to have fallen asleep or nodded off when driving at night compared to their male counterparts (4%), although in sum, the extent of this occurring 'sometimes' among males was higher than that of females (21% vs 17%, respectively). Female drivers (48%) also reported a slightly higher frequency of experiencing lapses of concentration compared to males (39%). Negligible differences were found between male and females drivers in terms of how often they experience highway hypnosis or struggle to keep their eyes open while driving at night. However, for both of these categories, male drivers were shown to have experienced these issues to a greater extent than female drivers.

Driver age

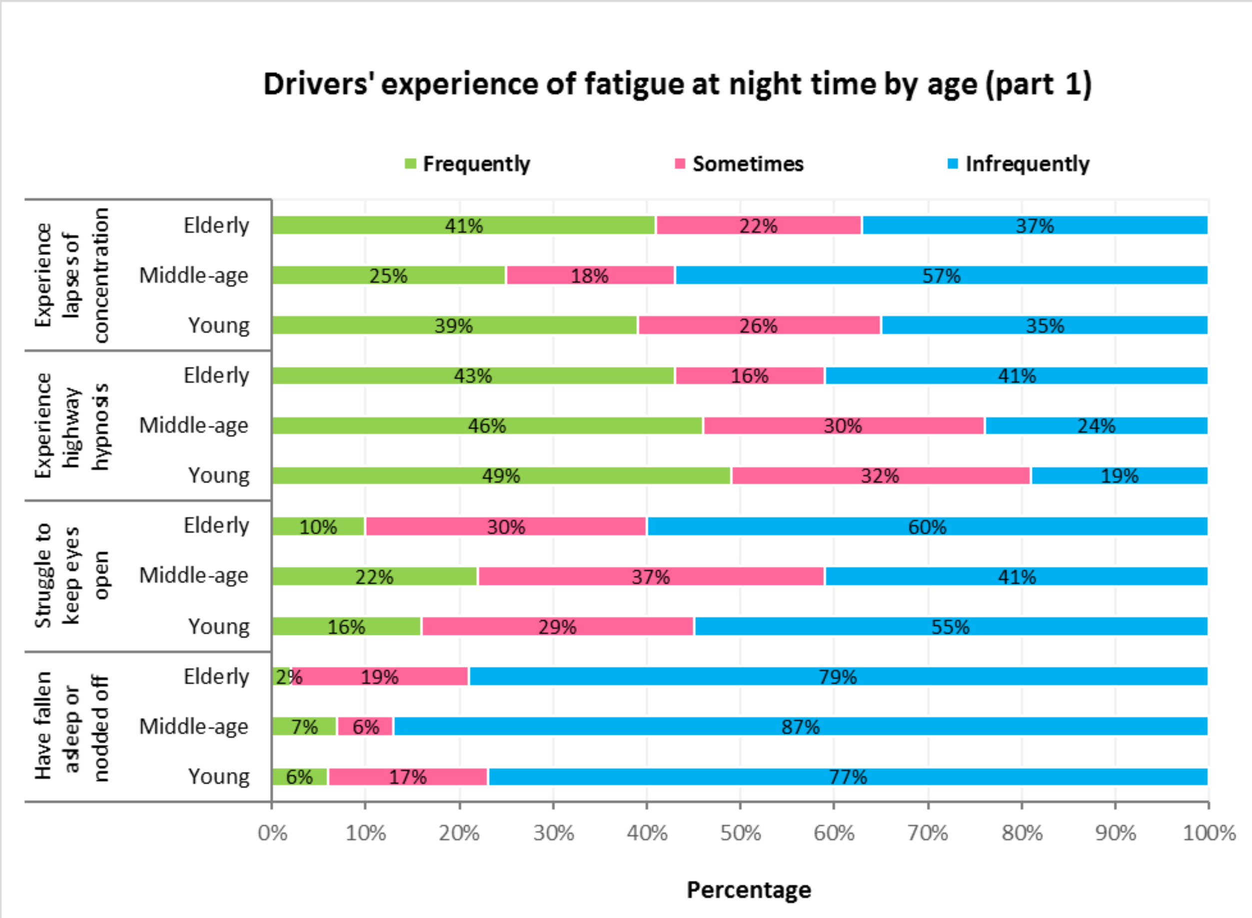


Figure 4-52: Drivers' experience of fatigue at night time by age (part 1)

Drivers' experience of fatigue at night time was analysed according to age and the first part of the results are shown in Figure 4-52. Experiencing lapses of concentration while driving at night occurred most frequently among elderly drivers (41%), followed by young drivers (39%) and middle-age drivers (25%). While marginal differences were found between drivers' experience of highway hypnosis at night, young drivers (49%) showed the greatest propensity for having no clear recollection of the road travelled on at night followed by middle-age drivers (46%) and elderly drivers (43%). Middle-age drivers were more likely to frequently or sometimes struggle to keep their eyes open while driving at night, followed by young drivers and elderly drivers (59% vs 45% vs 40%, respectively). In terms of falling asleep or nodding off while driving at night, elderly drivers (2%) reported the lowest frequency of this behaviour, followed by young drivers (6%) and middle-age drivers (7%). However, the extent of this occurring was the highest for elderly drivers (19%), followed by young drivers (17%) and middle-age drivers (6%). Overall, falling asleep or nodding off occurred ‘frequently’ or ‘sometimes’ more often among young drivers (23%), followed by elderly drivers (21%) and middle-age drivers (13%).

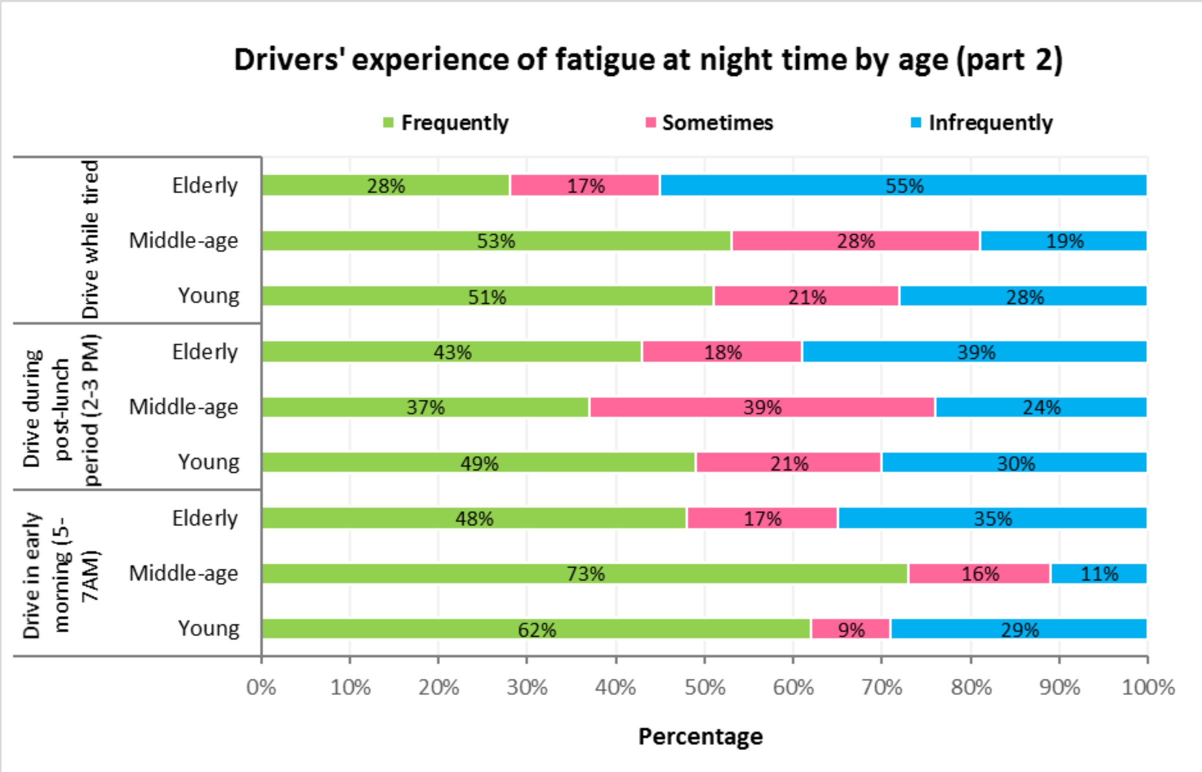


Figure 4-53: Drivers’ experience of fatigue at night time by age (part 2)

The second part of the results concerning drivers’ experience of fatigue at night time according to age, is shown in Figure 4-53. A larger proportion of middle-age drivers (53%) indicated that they frequently drive while tired at night, followed by young drivers (51%) and elderly drivers (28%). In terms of driving during time periods when fatigue and sleepiness is known to be higher, young drivers (49%) drive more frequently during the post-lunch period and middle-age drivers (73%) drive more frequently during the early hours of the morning.

4.4.5.1 Fatigue countermeasures

Drivers were also asked about the measures they adopt to counteract the feelings of fatigue while driving at night. Figure 4-54 shows the results obtained for all drivers and Figure 4-55 shows the results according to driver gender, driver age and driving experience.

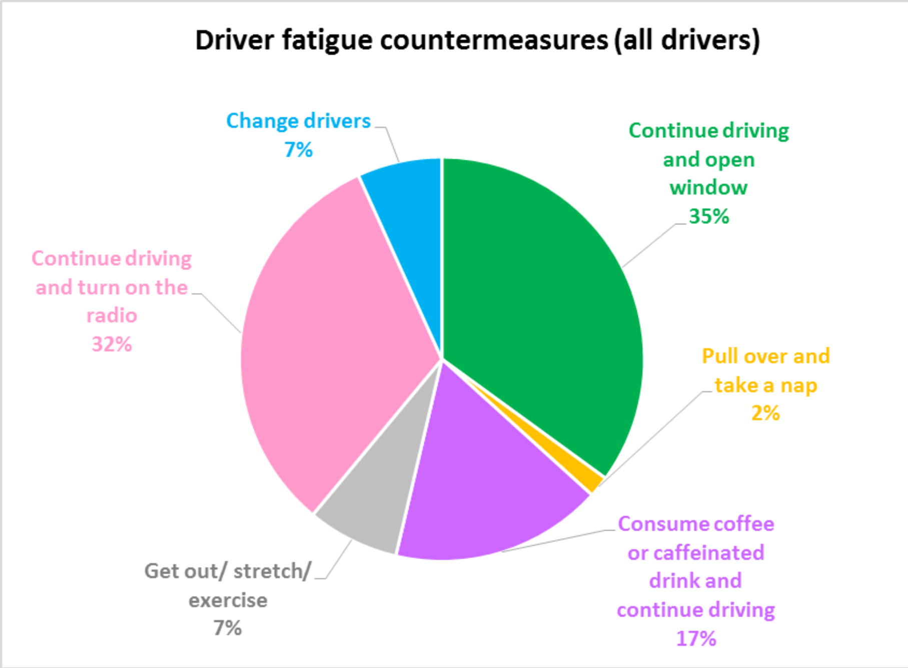


Figure 4-54: Driver fatigue countermeasures (all drivers)

Overall, the countermeasure most often adopted to counteract the experience of fatigue at night is 'continue driving and open a window' (35%) followed by 'continue driving and turn on the radio' (32%). The fatigue countermeasure least adopted by drivers is to 'pull over and take a nap' (7%).

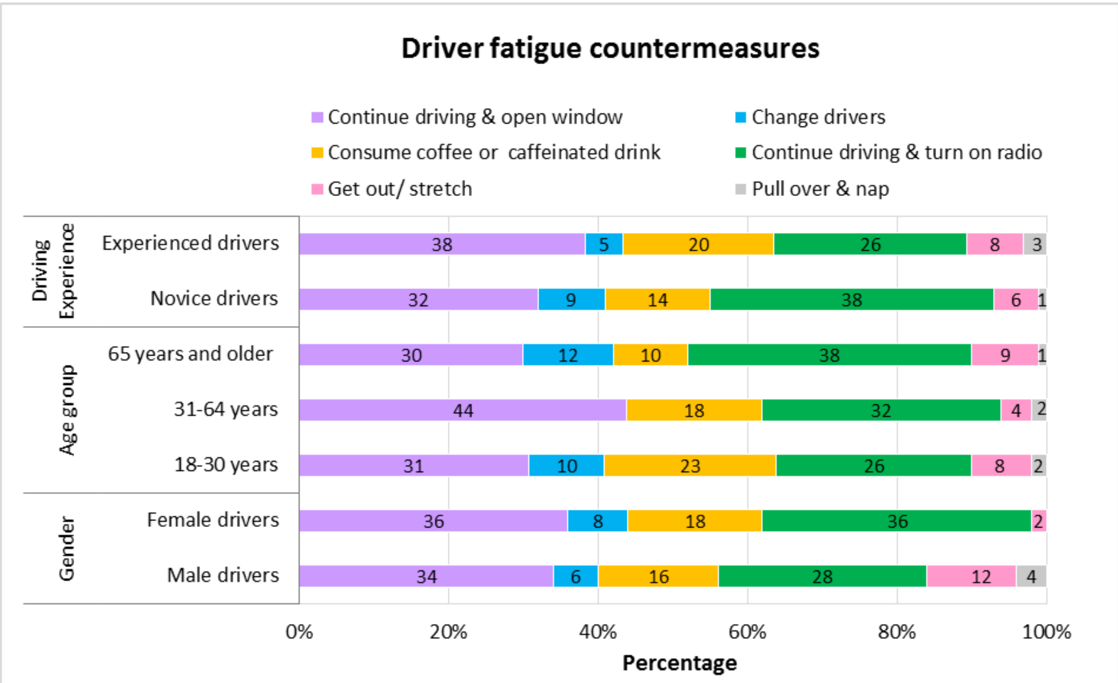


Figure 4-55: Driver fatigue countermeasures by gender, age and driving experience

The countermeasure most frequently adopted by male drivers (34%) was to 'continue driving and open a window' while female drivers adopted the countermeasure 'continue driving and open a window' (36%) and 'continue driving and turn on the radio' in equal proportions. Female drivers (8%) also showed a slightly higher propensity to 'change drivers' to counteract fatigue compared to male drivers (6%). Conversely, male drivers (4%) were more likely to 'pull over and take a nap' than their female counterparts (0%). In terms of age, the countermeasure most frequently adopted by elderly drivers was 'continue driving and turn on the radio' (38%) while middle-age drivers and young drivers more frequently 'continue driving and open window' (44% and 31%, respectively). Elderly drivers and young drivers showed similar propensity to 'change drivers' (12% vs 10%, respectively) as well as 'get out and stretch' (9% vs 8%, respectively). The countermeasure most frequently adopted among novice drivers (38%) was 'continue driving and turn on radio' while experienced drivers (38%) adopted the countermeasure 'continue driving and open window' more frequently.

4.4.6 Driver violations and aberrant driving behaviour

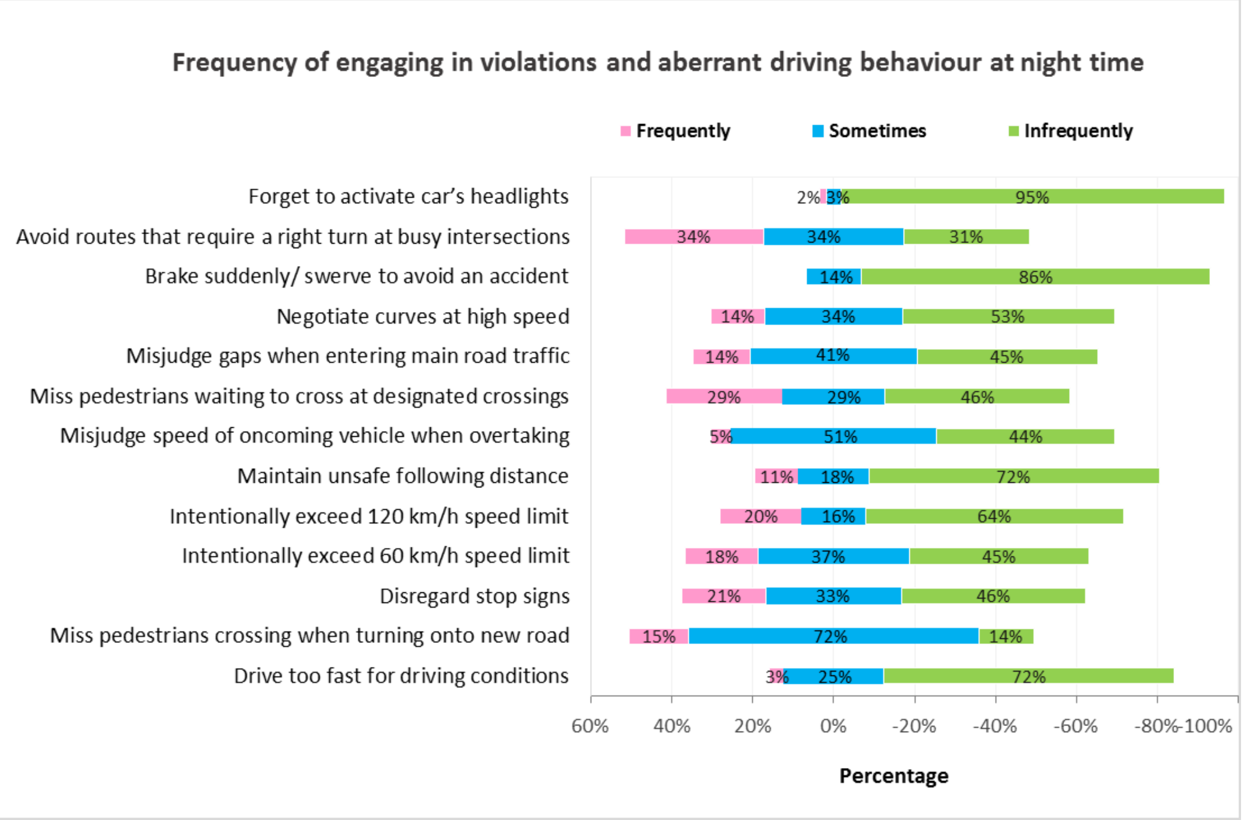


Figure 4-56: Frequency of engaging in aberrant driving behaviour at night time

Drivers were asked to rate the frequency of engaging in aberrant behaviours and traffic violations at night. The results for all drivers are shown in Figure 4-56. In terms of speeding, the majority of drivers (72%) indicated that they do not drive too fast for the driving conditions while 25% of drivers indicated that they so occasionally and 3% of drivers indicated that they do so frequently. Drivers deliberately drive above the speed limit more frequently on 120 km/h roads (64% of drivers) compared to 60 km/h roads (45% of drivers). Disobeying traffic control signs such as stop signs were also common, with 21% of drivers indicating that they frequently disregard stop signs and 33% of drivers indicating that they occasionally do so. A slightly higher number of drivers indicated that they negotiate curves at a high speed during night time, with 14% of drivers indicating they do so frequently and 34% of drivers indicating that they do so occasionally. Errors in depth and speed perception were also frequent at night.

With regards to speed estimation, 51% of drivers indicated that they sometimes misjudge the speed of oncoming vehicles when overtaking and 5% of drivers indicated that this is a frequent occurrence. With regards to depth perception, 41% of drivers indicated that they occasionally misjudge gaps when entering main road traffic and 14% indicated that this occurs frequently. In terms of pedestrian detection at night, 29% of drivers frequently fail to see pedestrians waiting to cross at designated crossings, while 25% of drivers occasionally overlook pedestrians. Seeing pedestrians crossing when turning onto a new road also appears to be challenging for drivers, with 72% of drivers indicating that they have occasionally missed pedestrians and 15% of drivers indicating that they have frequently missed pedestrians crossing when turning onto a new road.

4.4.7 Headlight usage at night

Drivers' choice of beam setting (high/low) under hypothetical driving circumstances at night was investigated. The hypothetical driving scenario consisted of driving along a straight, rural road with a few slight curves, little to no street lighting and minimal traffic in the oncoming lane. Drivers were asked to state their preference for low or high beams under these driving conditions. Figure 4-57 shows the vehicle beam setting preference for all drivers.

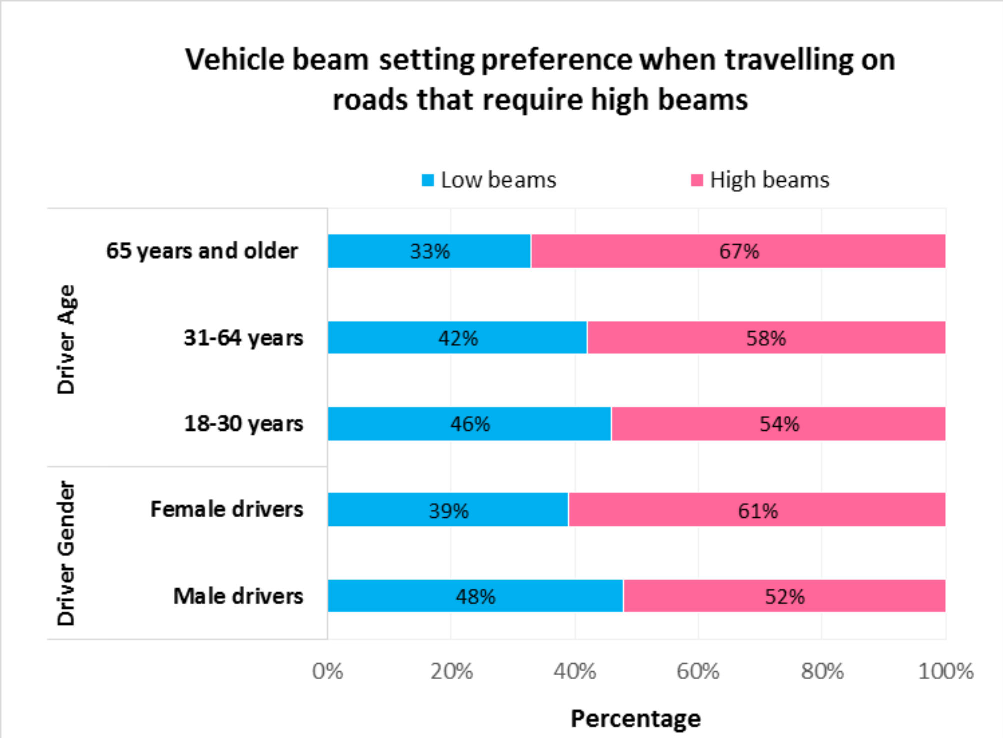


Figure 4-57: Vehicle beam setting preference when travelling on roads that require high beams

The majority of drivers indicated they would use high beams during circumstances that require and justify high beam usage. In terms of age, high beams were more preferable among elderly drivers (67%) and least preferable among young drivers (54%). Female drivers (61%) showed a slightly greater orientation toward high beams compared to male drivers (52%).

In addition to this beam setting preference at night, drivers were also asked to indicate the reasons which would be most appealing to choosing low beams at night (whether they selected this option or not) by means of ranking options supplied. This was used to understand why drivers choose low beams in situations that require and justify high beam use. Table 4-15 shows the reason for low beam usage according to driver age.

Table 4-15: Reasons for low beam preference

Rank	Young	Middle-age	Elderly
1	Get tired from switching between beam settings	Forget to activate high beams after car has passed	Afraid of forgetting to revert to low beams and may cause an accident
2	Forget to activate high beams after car has passed	Get tired from switching between beam settings	Forget to activate high beams after car has passed
3	Believe there is little or no difference between visibility offered from low/ high beams	Afraid of forgetting to revert to low beams and may cause an accident	Get tired from switching between beam settings
4	Afraid of forgetting to revert to low beams and may cause an accident	Believe there is little or no difference between visibility offered from low/ high beams	See better with low beams than high beams
5	See better with low beams than high beams	See better with low beams than high beams	Believe there is little or no difference between visibility offered from low/ high beams

According to the results, the primary reason for choosing low beams instead of high beams differs among drivers but is mainly attributed to inconvenience of switching between beams, forgetting to activate high beams and concern about forgetting to change from low beams to high beams and causing an accident. The main reason why young drivers use low beams for the majority of the time is that they get tired from switching between beam settings. For middle-age drivers, using low beams for the majority of the time is preferable because they forget to activate their high beams after car oncoming cars have passed by. Elderly drivers primarily choose low beams because they are afraid of forgetting to revert to low beams and consequently cause an accident.

4.4.8 Driver task difficulty at night

Drivers' level of difficulty with certain driving tasks at night was investigated and the results are displayed in Figure 4-58.

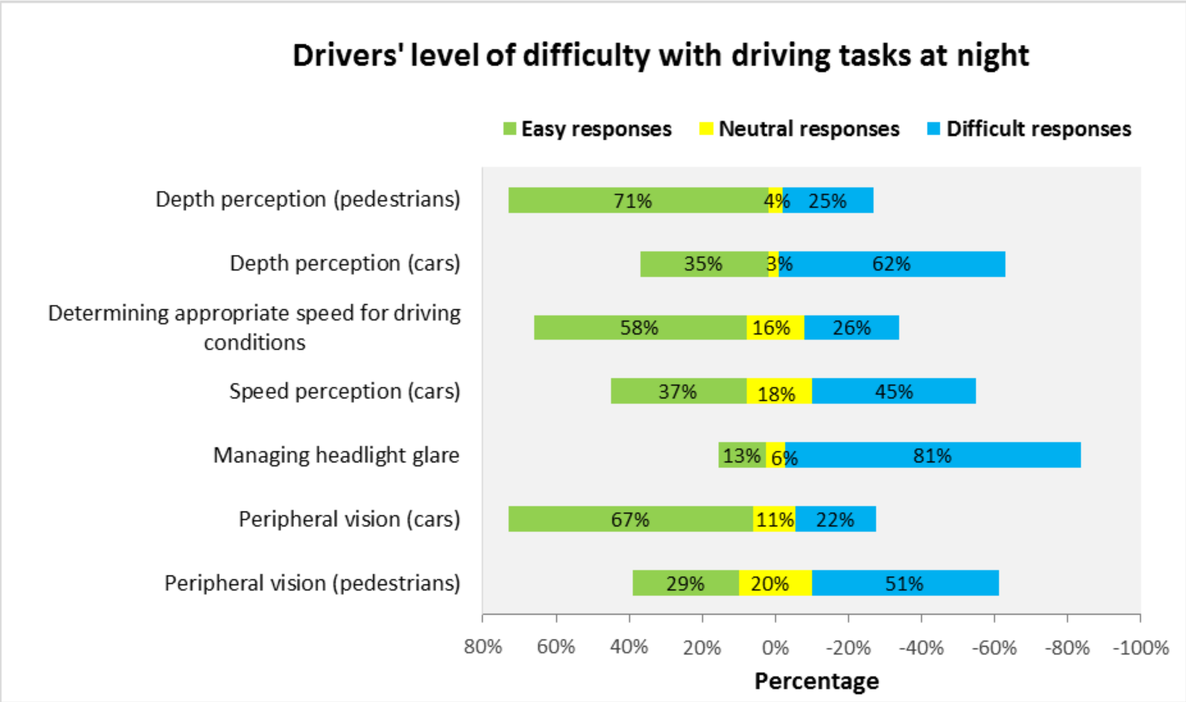


Figure 4-58: Drivers' level of difficulty with driving tasks at night

Overall, the most challenging task at night time is managing headlight glare from oncoming vehicles (81% of drivers). With regards to depth perception, a higher number of drivers (62%) experience difficulty judging the distance between themselves and other moving cars while a slightly smaller proportion of drivers (25%) have difficulty judging the distance between themselves and pedestrians. In terms of speed perception at night, 45% of drivers indicated that they find it very difficult noticing when the car in front of them is speeding up or slowing down while 58% of drivers indicated that they find it easy to determine what the appropriate speed is for the driving conditions. With regards to peripheral vision, an opposite trend was observed to that of depth perception with drivers reporting greater difficulty in seeing pedestrians in the peripheral view than other motorists. In terms of pedestrians, 51% of drivers indicated they experience difficulty seeing pedestrians cross form the side until they are right in front of them. For other motorists, 22% of drivers indicated that they experience difficulty seeing cars moving from the side until they are right in front of them.

Chapter 5: Discussions

5.1 Introduction

This chapter discusses the results obtained from the research and presented in chapter 4. Findings from the crash and fatality data sets are discussed first, followed by the results obtained from the driving videos and finally, the results from the night driving survey are discussed.

5.2 Road Traffic Crashes and Road Traffic fatalities

5.2.1 Hourly RTC and RTF trends

A higher proportion of crashes occurred during daytime (73%) while a relatively smaller number of crashes occurred during night time (20%). A number of factors can explain the disparity between the number of crashes recorded for daytime and night time. Firstly, most road users tend to occupy the roads during daytime conditions and as a result, higher traffic volumes are present during daytime compared to night time. As traffic flow increases the number of interactions among road users also increase which lead to increased opportunities for potential traffic conflicts and ultimately, crashes. Appendix B presents data that shows the hourly traffic flow variation on major roads in Johannesburg, South Africa in 2015 (Sampson, 2017). From this graph, it is evident that traffic flows are relatively higher during daytime hours (06:00 AM to 06:00 PM) compared to night time hours (06:00 PM to 06:00 AM). High traffic volumes are not characteristic of night time, which accounts for the significantly lower crash incidence reported during this period.

While it is intuitive that more crashes occur when people are in transit, the relationship between crash frequency and traffic volume has also been studied empirically. In their literature study on the impact of traffic volumes on crash occurrence at major arterials and highways, Chang & Xiang (2003) reported that in general, an increase in traffic volumes results in an increase in crash frequency. Additional studies investigating the relationship between crash occurrence and traffic volume were undertaken by Hiselius (2004) and Martin (2002) for hourly traffic volumes on rural roads and highways, respectively. Their findings indicate that although the precise nature of the relationship between crash occurrence and traffic volume is unclear, higher crash frequencies are observed when traffic increases.

In addition to greater exposure to crash opportunities during daytime, research has shown that road users are more likely to become impatient and aggressive during peak traffic hours, resulting in increased tendencies to engage in risky driving behaviour such as risky overtaking manoeuvres, cutting across one or more lanes in front of other vehicles and driving on the shoulder (Emo, Matthews, & Funke, 2016 and Shinar & Compton, 2004). The increase in risky driving behaviour during daytime conditions results in a greater chance of being involved in a crash which may also elucidate the higher crash frequencies observed during daylight periods.

The decline in traffic crashes at night is reflective of reduced traffic volumes. Precise quantification of traffic volumes at night for the City of Cape Town were not available but when looking at the hourly traffic flow variation in Appendix C, it is evident that during night time hours, traffic volumes are lower relative to daytime. Presumably, a reduction in crashes would translate into a reduction in traffic fatalities at night since crashes and crash opportunities are significantly lower during this time. Conversely, a slightly higher number of traffic fatalities occur during night time (48%) compared to day time (42%). To some extent, these finding are surprising given that traffic and lighting conditions differ greatly at day and night. Furthermore, relative to crashes (20%) at night, the frequency of fatalities (48%) is more than double the number of crashes. These results show that even though crashes are significantly lower at night, fatalities are higher. The higher fatality frequency indicates that injury severity outcomes are more likely to be fatal during night time and that while the risk of a crash is reduced; the risk of sustaining fatal injuries in the event of a crash is elevated during night time.

These results are consistent with several other studies that show higher fatal crash involvement rates and higher injury severity rates at night time (Verghese & Shankar, 2007). Earlier studies by Herd, Agent & Rizenbergs (1980) report that the severity of crashes was higher on two-lane and four-lane freeways in urban areas during night time compared to daytime. Injury-type crashes were also reported to have increased under conditions of darkness, with the proportion of fatal crashes almost four times higher at night time relative to daytime. Subsequent studies by Massie & Campbell (1993) examined mileage-based crash rates according to light condition. They found that that when crash rates were calculated per mile driven, the night time fatal crash involvement rate for drivers of all ages was 4.6 times higher than the fatal crash involvement rate at daytime. More recently, similar results were obtained by Plainis, Murray & Pallikaris (2006) who reported that the severity of crashes double during night time when compared to daytime and by Verghese & Shankar (2007) who reported a three-fold increase in the fatality rate at night relative to daytime.

The greater incidence of traffic fatalities observed at night is evidence that night time conditions pose a greater danger to road users. This can be attributed to changes in illumination brought on by night time which indicates that darkness is a hazardous time for road travel. While some of this risk is derived from visual losses and the degraded visibility conditions drivers contend with as they navigate the road environment at night time, fatal crash risk is also exacerbated by other secondary factors such as alcohol use, fatigue, driving speed and traffic flows. Alcohol use, driving while fatigued and adopting higher speeds (owing to a false sense of safety perceived by lower traffic volumes among other factors) is known to increase at night time and has been consistently documented in the literature as increasing the risk of crashes and the severity of crashes at night time. Rice, Peek-Asa and Kraus (2003) reported that drivers were 40 times more likely to be in a severe or fatal crash following alcohol consumption. Crash rates attributed to alcohol use were also reported to increase with advancing night hours. Furthermore, in their study on BAC level and fatal crash involvement at day and night time, Verghese & Shankar (2007) reported that of the 15 878 crashes in their sample, 60% of crashes involving alcohol occurred during night time. In terms of fatigue, humans are typically sleepier at night and sleep deprivation has been reported to be a contributory factor in up to 20% of traffic crashes and 50% of fatal traffic crashes (Wilson *et al.*, 2006). The reason for this substantial risk is attributed to reduced vigilance and alertness, slower response time as well as to the fact that drivers in these conditions adopt higher speeds and are not able to swerve or break in the event of a crash or imminent obstacle (Horne, Reyner, Cook, & Albery, 1995).

With regards to speed behaviour, research has shown that the risk of being killed and sustaining severe injuries is greater at higher speeds. High speeds play a major role in injury severity outcomes and can possibly explain the high number of fatalities at night. High speeds may especially account for the high number of fatalities at night time since some studies have reported little to no difference in speed behaviour at day and night time Quaium (2010), while other studies have reported higher speeds at night time (Bassani & Mutani, 2012). Overall, these studies indicate that drivers' do not greatly adjust their speed behaviour to compensate for visual losses at night. This may be due to an effect of traffic flows since higher traffic volumes inhibit speeding and increase risk perception. While speeding, fatigue and alcohol use pose a risk to drivers at any time of the day, engaging in these behaviours during dim lighting conditions increases crash risk and deteriorates crash outcomes to a greater extent which may account for the rise in traffic fatalities at night.

When analysing road traffic crashes according to hour of the day, the data reveal that most crashes occur at 05:00 PM, 04:00 PM and 07:00 AM, respectively. Given that these hours characterise peak traffic periods, it is expected that most crashes would occur at this time. The rise in crashes during the mid-afternoon period between the hours of 03:00 PM and 02:00 PM respectively can be explained by two reasons. Firstly, the mid-afternoon period precedes the afternoon peak traffic period (04:00 PM – 06:00 PM). As a result, the higher number of vehicles on the road during this time can lead to greater exposure to crash opportunities which results in greater crash frequency.

Secondly, the higher number of crashes during this periods may also be caused by a dip in alertness as the circadian rhythm in sleepiness is believed to peak during this time of the day (Van Dongen & Dinges, 2000). Other research studies have also reported mid-afternoon crash peaks. In their study on sleep-related vehicle crashes, Horne et al. (1995) observed a peak in mid-afternoon crashes in the United Kingdom, with peaks occurring between 02:00 PM - 04:00 PM. Similar trends of sleep-related vehicle crashes peaking during the mid-afternoon period have also been reported for the United States (Pack et al., 1995), Israel (Zomer & Lavie, 1990), Finland (Summala & Mikkola, 1994) and France (Philip, Ghorayeb, Stoohs, Menny, Dabadie, Bioulac & Guilleminault, 1996).

Another rise in crashes occurs around 12:00 AM, where the increase in the frequency of crashes is almost twofold in the preceding hour (11:00 PM) and almost three-fold in the succeeding hour (01:00 AM). Primarily, the sharp increase in crashes at 12:00 AM can be attributed to alcohol consumption and to a lesser extent fatigue, as this is the time of the night time period that drivers are most likely to be driving while intoxicated and experiencing becoming drowsy. This explanation has consistently been supported by previous studies. A report by the National Highway Traffic Safety Administration reported that midnight to 03:00 AM is the time with the highest percentage of crashes. During this period, two-thirds of crashes are caused by drink driving (NHTSA, 2011). In terms of fatigue, in their analysis of crashes caused by drivers falling asleep at the wheel, Pack et al. (1995) observed peaks in crashes from midnight- 06:00 AM and 02:00 AM-03:00 AM. More recently, the NHTSA also estimates that 100 000 police-reported crashes are caused by driver fatigue each year which commonly occurs between the hours of 12:00 AM - 02:00 AM, 04:00 AM - 06:00 AM and 02:00 PM - 04:00 PM (NHTSA, 2011).

When analysing road traffic fatalities according to hour of the day, the data reveal that the most dangerous hours for driving are 08:00 PM, 07:00 PM and 09:00 PM, respectively. The high number of fatalities observed during these periods is most likely caused by the effect of poor visibility and traffic volumes (although the impact of traffic volumes is expected to be smaller, since traffic volumes are lower during these periods). This is further confirmed when looking at the number of fatalities occurring in the early morning. Given that the traffic conditions in the early morning (01:00 AM – 05:00 AM) and early afternoon (01:00 PM - 05:00 PM) are vastly different, the similarity in fatality frequencies is alarming and points to the increased danger brought of driving at night time. This increased risk can also be attributed to poor visibility, driving while impaired by fatigue or alcohol and adopting higher speeds at night.

5.2.2 RTCs and RTFs according to illumination condition

Road traffic crashes and fatalities during twilight periods account for 11% of all traffic crashes and 15% of all traffic fatalities. The difference in crashes during the evening twilight and morning twilight is nearly two-fold for traffic crashes and are exactly two-fold for traffic fatalities. The evening twilight period was found to have more crashes than the morning twilight period and this trend was observed for both RTCs and RTFs. Evening nautical twilight was also reported to have more crashes compared to the other twilight periods. Compared to traffic crashes, the frequency of fatalities during each twilight period increased (except for morning nautical twilight and evening astronomical twilight) and this indicates that fatality risk is higher during twilight periods, compared to crash risk.

Crashes during twilight periods often coincide with peak traffic periods (06:00 AM – 08:00 AM for the morning peak traffic period and 04:00 PM – 06:00 PM for the evening peak traffic period). As a result, these crashes can also be attributed to higher traffic volumes. However, twilight periods vary depending on the season which means that twilight may occur before or after established peak traffic periods. Analysing crashes that occur during twilight periods but that fall outside of peak traffic periods can isolate the ‘twilight effect’ to examine the impact of changing visibility conditions on road traffic crashes and fatalities.

The results show that the proportion of crashes during the early morning (04:00 AM – 05:00 AM) and early evening (06:00 PM – 08:00 PM) fall within twilight periods but outside of established peak traffic periods, with evening twilight displaying the highest crash frequency. These crashes cannot wholly be attributed to traffic conditions since they occur outside of peak traffic hours (although it could be argued that more people are on the road during this time since the sun sets later). While this is a reasonable assumption, the increase in traffic will not be comparable to peak traffic periods which indicates that changing illumination conditions during twilight periods pose a danger for drivers. Furthermore, these results imply that when twilight periods coincide with peak traffic periods, drivers are also at an increased risk of being in a crash since visibility is compromised and crash opportunities are also increased. These findings support the notion that drivers crash and fatality risk during twilight periods are not solely due to traffic volumes but difficulty in adapting to changing ambient light conditions as well.

The frequency of crashes and fatalities occurring during twilight periods (and in particular evening nautical twilight) can be attributed to the transition in ambient light conditions from light to darkness. When ambient illumination becomes darker, drivers’ eyes have to adapt to the changing level of brightness. During this process, cones weaken in efficiency and they cannot register sharp vision and rods- despite being superior at night time- are still adjusting to night mode. Both light-sensitive cells are compromised during dark adaptation and perform inefficiently. This transition period is challenging for drivers’ eyes to adjust to and can explain the crashes occurring during twilight periods.

Even though there is more ambient light present during twilight periods, seeing during twilight is possibly more difficult than seeing during complete darkness. This is because during twilight; the eye is still adjusting and the rods have not been completely activated for night vision but during complete darkness; the dark adaptation process is completed and rods have reached maximum retinal sensitivity. Given that vision is somewhat compromised during twilight, it is expected that drivers will adjust their driving behaviour by reducing their speed with the onset of twilight and not only when the period of night time commences. However, in their study on the effect of light conditions on vehicle speed Jägerbrand &

Sjöbergh (2016) reported negligible speed differences between daylight, darkness, daylight twilight and dark twilight. The lack of risk compensation for visual losses may be owing to the fact that drivers are unaware of visual limitations experienced during twilight. In addition, illumination during twilight periods is relatively brighter when compared to night time which may result in lower risk perception and drivers not recognising the need to adjust speed behaviour. The lack of speed adjustment reported during twilight periods in conjunction with poorer vision can therefore also account for the crashes occurring during twilight periods.

Apart from visual inefficiencies during twilight, driving during these periods also poses a risk to drivers because, although the sky is still lit, the road is darker and there is a reduction in contrast in the rest of the scene. The cones are also not as perceptive and sharp in picking up detail and colour. Less contrast in colours make recognising oncoming vehicles and pedestrians more difficult which results in longer stopping distances. Furthermore, measures to counteract the poor visibility experienced during this period by activating vehicle headlights are also limited since natural light is reduced but the sky is not dark enough for the headlights to be completely effective.

Higher crash and fatality rates were observed for evening twilight compared to morning twilight. These results suggest that it is more difficult for drivers to adjust from light to darkness than vice-versa. Similar results have previously been reported by Owens & Sivak (1996) who observed that the frequency of road fatalities is disproportionality higher during the darker phase than the lighter phase of the twilight zone. These results are explained by understanding how rod and cone receptors function during light and dark adaptation phases. In short, cones adjust much quicker to light and darkness than rods. During evening twilight, rods (primarily used during night time) adapt much slower to darker illumination (approximately 30 minutes). During morning twilight, cones (primarily used during daytime) adapt much faster to brighter illumination (approximately five minutes). This means that drivers' eyes adjust much quicker to light during morning twilight than evening twilight and that inefficiencies in vision prevail for a longer period during the evening twilight than morning twilight. Hence, a higher number of crashes and fatalities are observed during evening twilight relative to morning twilight.

Another human factor that can explain the discrepancy in crash and fatality incidence during morning and evening twilight is fatigue. Given that drivers are subjected to the same visibility conditions during the morning and evening twilight periods and that traffic volumes are both low during this time period, the only other factor influencing the increased crashes during evening twilight is the condition of the driver. During evening twilight, drivers are usually on their way home and typically experience exhaustion and fatigue which affects concentration and reaction time. Compromised visibility in conjunction with fatigue is known to dramatically increase crash vulnerability. In the morning twilight periods, drivers are refreshed and rested which results in increased vigilance and the ability to react to hazards in the road environment.

5.2.3 RTCs according to crash type

While the causes of crashes are not provided in the dataset, there are contributory factors common among night time crashes which include fatigue. Traffic crashes that occur late at night or early in the morning are typically attributed to sleep deprivation in the literature. A rise in fatigue-related crashes have consistently been observed from midnight to 6:00 AM by a number of previous studies (Armstrong et al., 2008; Horne & Reyner, 1999; Pack et al., 1995; Palamara, 2017). To identify fatigue-related crashes in crash data, proxy definitions are typically applied post-hoc to crash reports (Armstrong et al., 2011; Filtness et al., 2017; Palamara, 2017). Examples of these proxies include ‘vehicle ran off the road and/or crashed with another vehicle or object’, ‘head-on crashes in the absence of overtaking manoeuvres’ and crashes on roads with a speed zone of 60 km/h or less (Armstrong & Smith, 2008; Palamara, 2017). The most important criteria required to attribute these types of crashes to fatigue is that they have to occur between midnight and 6:00 AM. In the present analysis, crashes with fixed/other object are prevalent throughout the day and early evening period. However, at night these crash types are dominant at midnight and the early morning period. Given that fatigue is more pronounced in drivers during this period of the night time, these crashes may be an effect of fatigue. However, in the absence of substantive evidence linking these crashes to sleep deprivation this claim is not decisive. At the very least, these results indicate that late at night and early in the morning, drivers are involved in more crashes with a fixed/ other object which may be caused by fatigue or other factors.

5.2.4 RTFs according to age, gender, race and road user

Both gender categories have higher fatalities during night time hours compared to daytime. The frequency of fatalities for males during night time is 78% and the frequency of fatalities for females is 22%. This indicates that traffic fatalities for males were substantially higher than traffic fatalities for females during night time conditions. Furthermore, during night time hours, the rate of male's fatal crash involvement is almost four time times higher than females. In terms of age, fatalities during night time were higher among young road users (55%) followed by middle-age road users (49%) and elderly road users (40%).

In terms of drivers, from the age of 25 years old fatalities among drivers decline with advancing age for both male and females at night time. Compared to daytime, traffic deaths for young and middle-age drivers increase substantially at night time. Conversely, elderly drivers have lower traffic deaths at night compared to daytime. Young drivers (54%) have the highest frequency of traffic deaths followed by middle-age drivers (35) and elderly drivers (11%). Young male and female drivers overwhelmingly demonstrate higher traffic fatalities compared to middle-age and elderly drivers. For young male drivers the ratio of night time to daytime traffic fatalities is consistently high, with traffic fatalities in 20-24 age categories twice as high at night time relative to daytime. For young female drivers the ratio of night time to daytime traffic fatalities is also predominantly high, with traffic fatalities in 25-29 year age category 1.9 times higher at night time relative to daytime. The results indicate that young drivers are more vulnerable to traffic fatalities at night time, with male drivers experiencing greater risk compared to female drivers.

In terms of pedestrians, similar to the trends observed for drivers, pedestrian fatalities generally decline as age increase for males and females at night time. Compared to daytime, traffic fatality rates at night time are higher for young and middle-age pedestrians. Child and elderly pedestrians on the other hand, show higher fatality rates during daytime. At night time, young pedestrians (42%) have the highest frequency of traffic deaths, followed by middle-age pedestrians (37%) and elderly pedestrians (12%). For young male pedestrians the ratio of night time to daytime traffic fatalities is consistently high, with traffic fatalities in 30-34 age categories 1.56 times higher at night time relative to daytime. For middle-age female pedestrians, the ratio of night time to daytime traffic fatalities is also predominantly high, with traffic fatalities in 40-44 year age category 1.81 times higher at night time relative to daytime. The results indicate that young male pedestrians and middle-age female pedestrians are more vulnerable to traffic fatalities at night time.

These results show that all road user groups face considerable risk of being involved in a fatal crash at night time. Young road users demonstrate the highest risk and this can be attributed to exposure and a greater tendency for these road users to occupy the roads at night coupled with a higher incidence of alcohol use and risk-taking behaviour at night. Middle-age road users also demonstrate high fatal injury risk at night time, though this is not as high as that of young road users. Elderly road users constitute a lesser proportion of fatal injuries occurring at night time and this may be due to decreased exposure to the traffic environment at night. Previous studies have indicated that elderly drivers are less likely to occupy the roads at night due to travel patterns, poor night vision and a greater awareness of visual limitations at night (Zhang et al., 1998). However, the peak in fatalities for the age category 55-59 years old confirms that when this road user group does occupy the roads at night the risk of being involved in a fatal crash is comparable to that of middle-age road users. These findings are in line with several studies which show that young road users demonstrate higher fatal injuries compared to middle-age and elderly road users (Dissanayake, 2004; Dovom et al., 2013).

Several research studies have confirmed that males face considerably higher risk of being involved in a traffic crash and fatality compared to females (Mortimer & Fell, 1989; Rice et al., 2003; Swedler et al., 2012). Yagil (1998) observed that the rate of fatal crash involvement for males was reported to be twice as high compared to females. In terms of road user category, several studies confirm that male road users are over-represented in fatal crashes as drivers (Eustace & Wei, 2010; Ginpil & Attewell, 1994), pedestrians (Onieva-García, Martínez-Ruiz, Lardelli-Claret, Jiménez-Moleón, Amezcua-Prieto, de Dios Luna-Del-Castillo & Jiménez-Mejías, 2016; Zhu, Zhao, Coben & Smith, 2013) and cyclists (Prati et al., 2017; Tin Tin et al., 2010). The findings that males road users are more vulnerable to fatal crashes at day and night time than their female counterparts is therefore, not unexpected. Higher fatality rates among males can be primarily related to exposure. Males are more likely to drive, walk and cycle and for longer periods of time compared to females (Zhu *et al.*, 2013). This factor, combined with greater orientation towards risk and greater consequences for risk-taking behaviour (Al-Balbissi, 2003), also accounts for the higher fatality rates at night among males.

In terms of drivers, the frequency of fatal crash involvement among drivers varies as a function of driver age. Apart from the peak in the age group 20-24, fatalities among drivers appear to decline with increasing age. Several studies have shown a strong association between night time driving and higher crash occurrence among young drivers (Bates et al., 2014; Massie et al., 1995; Ryan et al., 1998; Swedler et al., 2012; Williams, 1985). High fatality rates among young drivers can be attributed to higher exposure to the risk of being involved in a crash (i.e. they tend to drive more), a lack of driving experience, higher incidence of alcohol use at night and a greater orientation toward risk and driving misdemeanours than middle-age and elderly drivers. Young drivers demonstrate the highest risk of fatal injury (48%, with the highest death rates occurring in the 25-29 age group) followed by middle-aged (38%, with the highest death rates occurring in the 40-44 age group) and elderly drivers (14%, with the highest death rates occurring in the 55-59 age group). These findings are consistent with other studies that have also reported high fatal crashes among young drivers (Zhang *et al.*, 1998). Young drivers are known to commit traffic violations, exceed the speed limit or drive too fast for driving conditions, drive while under the influence of alcohol, neglect to wear seat belts and engage in aberrant behaviour (Zhang *et al.*, 1998; Zhao *et al.*, 2014). These factors may be responsible for the high death rates observed among this road user group. A slightly less expected finding was the rate of fatal crash involvement for elderly drivers. It was expected that this frequency would be much higher since older drivers have poorer crash outcome as a result of age-related frailty. Other studies that have reported a higher rate of fatal injuries among older drivers compared to young and middle-aged drivers have been reported by Hanrahan, Layde, Zhu, Guse, & Hargarten (2009) and Massie (1995).

In terms of non-motorised modes, pedestrians constitute the largest proportion of night time fatalities, with young and middle-age males showing demonstrating the highest number of fatalities. These results indicate that pedestrian detection at night is a challenging task for drivers at night. While a number of pedestrian actions influence their crash risk at night, the primary reasons for the higher rates of fatalities is poor visibility at night (i.e. they are not always visible to drivers) and the lack of protection they have which makes them more vulnerable to sustaining life-threatening injuries in the event of a crash. These findings are in line with Shinar (2007) who reported that despite the lower exposure of pedestrians at night, most pedestrian crashes occur during hours of darkness compared to daylight. Fatal pedestrian crashes are overrepresented at night with more than half of all pedestrian fatalities occurring during darkness. Pedestrians are at an increased risk of being involved in a crash at night time. A study by Sullivan and Flannagan (2002) investigating the effect of ambient light on pedestrian crashes and vehicle crashes using the changeover in daylight savings time (DST), illustrated pedestrian vulnerability at night time. According to this study, pedestrians are up to 7 times more vulnerable in the dark and pedestrian fatal crashes are up to 4 times more likely in dark periods of daylight savings transition.

5.3 Naturalistic Driving Videos

5.3.1 Speed behaviour

The novice drivers in this study adopted higher speeds than the posted speed limit at night time on freeways and rural roads (100 km/h and 80 km/h). While the experienced drivers in this study did not adopt higher average speeds, the speeds chosen by these two drivers closely approximate the speed limit. Compared to the two experienced drivers, the two novice drivers adopted higher speeds across all road types. The speed behaviour observed for the two novice and two experienced drivers in this sample indicate that at night time they made no adjustment to their driving behaviour by reducing their speed. These drivers tend to choose a speed that is either higher than the speed limit or a speed that closely approximates the speed limit. Under low illumination, it was expected that the drivers observed in this study would decrease their speed to adjust to the risk factor of decreased visibility at night time. Surprisingly, in this study, drivers do not decrease their speed at night.

When comparing speed at day and night time, the results show that drivers adopted significantly higher speeds at night time compared to daytime. Relative to daytime, the speeds adopted at night time was twice as high for the novice drivers and almost twice as high for the experienced drivers. The greatest difference in speed for day and night time conditions was observed on freeways. During daytime, experienced drivers drove faster than novice drivers but at night the opposite trend was observed with novice drivers' driving faster than experienced drivers. The greatest increase in speed between day and night time was observed for novice drivers.

Previous research studies have shown that speed is one of the most frequently contributing factors to vehicle crashes. While there are additional factors that affect the relationship between speed and road traffic crashes, it is an established fact that the higher the speed of a travelling vehicle the greater the likelihood of being involved in a car crash and the greater the chance of sustaining life-threatening and permanent injuries in the event of a crash (Aarts & van Schagen, 2006; Afukaar, 2003). While speed per se is not a problem, excessive speed (when a driver exceeds the posted speed limit for a particular road) or inappropriate speed (when a driver adopts a speed that is not suitable for the prevailing road, weather, visibility and/or traffic conditions but within the speed limits) is a major contributing factor to road traffic crashes worldwide (Shinar, 2017; World Health Organisation, 2015). Higher speed exacerbates crash risk under night time conditions since visual reaction times are longer which translates into longer stopping distances (Plainis *et al.*, 2006). Adopting a speed close to the speed limit is also dangerous since it takes longer for drivers to recognise and react to hazards under darkness given that roadway illumination is severely degraded and vehicle headlights offer limited visibility. Although this sample size is small and further studies will be required to confirm the interpretations derived from it, the findings obtained from these drivers on speed behaviour at night are similar to previous studies that have also reported higher average speeds at night (Quaium, 2010, Valck, Quanten, Cluydts, & Berckmans, 2006, (Bassani & Mutani, 2012a) and in particular higher speeds at night for novice drivers (Senserrick, Scott-Parker, Buckley & Watson, 2016).

The lack of speed adjustment at night time can be attributed to a number of factors. Firstly, the drivers may be more inclined to choosing higher speeds at night because traffic volumes are lower (Hall & Pendleton, 1990). Although it was not possible to quantify traffic volumes from the driving videos, previous research studies have shown that the traffic volumes during night time hours (06:00 PM – 06:00 AM) are generally much lower compared to daytime hours (06:00 AM – 06:00 PM) (Sampson, 2017). Higher traffic volumes inhibit speeding which causes drivers to drive slower. This is based on research evidence that shows higher speed selection at night relative to daytime as well as higher speed selection on weekends relative to daytime which, among other factors, is a reflection of lower traffic congestion present on the roads during these periods (Ellison & Greaves, 2010).

Lower speed effected by higher traffic volumes is not only caused by more vehicles on the road and consequently fewer opportunities to engage in speeding, but also as a result of appropriate speed selection being dependent on the attentional demands of the driving situation (Senders, Kristofferson, Levison, Dietrich & Ward, 1967). In congested traffic conditions, the ‘information density’ of the road environment is higher; there is a larger amount of information to be processed, limited information about traffic in the drivers forward view and greater uncertainty about the behaviour of other road users and the possibility of encountering hazards, which requires drivers to select a speed that they can modify appropriately and timeously (Senders *et al.*, 1967). During uncongested traffic conditions, information density as it relates to traffic volumes is lower and drivers may be more prone to select higher speeds. In addition, the reduction in traffic volumes may also lower risk perception as drivers perceive the road environment to be less dangerous (since crash potentiality is minimised). This can also motivate higher speed choice at night. Finally, selecting higher speeds at night may be an adaptive behaviour to increase stimulation and counteract the feelings of fatigue as Törnros (1995) reported that when driving at 110 km/h compared to 70 km/h, drivers had faster reaction times and higher scores on subjective energy rating scales. Driving at higher speeds may therefore be a protective strategy to remain alert and to cope with the high task demands in monotonous driving conditions that characterises night time travel.

Not only do the drivers in this study not reduce their speed at night, but in the presence of road lighting an increase in speed was also observed for these drivers. All four drivers examined in this study showed an increase in speed when driving through an illuminated road section on a 100 km/h rural road, with the two novice drivers displaying the greatest increase in speed (speed increased by 11km/h) relative to experienced drivers (speed increased by 7 km/h). A similar trend was observed among the novice and experienced drivers when driving through an illuminated road section on an 80 km/h rural road, although the increase in speed was smaller compared to 100 km/h rural roads. Both novice and experienced drivers in this study increased their speed, with the novice drivers demonstrating a slightly greater increase in speed (speed increased by 5 km/h) relative to experienced drivers (speed increased by 4 km/h). These results show that the presence of road lighting has an impact on these drivers' perception and behaviour which causes them to respond by increasing speed.

There can be little doubt that road lighting is a powerful and useful traffic crash countermeasure and is known to have tremendous crash-reducing effects for drivers (Beyer & Ker, 2009a) and particularly, for pedestrians at night (Wanvik, 2009a). Road lighting improves visibility, the driver's visual capabilities at night (enhances visual acuity and visual discrimination ability) and the ability to react to roadway hazards in time. However, as the results above indicate and literature has confirmed; road lighting can also have an adverse effect on drivers as they tend to use the advancements in road luminance at night time as an opportunity to increase their speed. The two novice and experienced drivers in this study may have increased their speeds when street lighting was present because the gain in visibility allows them to see at greater distances which make them feel safer and more confident about reacting to roadway hazards in time. When visibility was restricted again they reverted back to lower speeds and this shows that these drivers acknowledge the need to reduce speed when visibility is decreased. Although the reduction in speed is not sufficient to compensate for visual losses at night, it indicates that these drivers are able to adjust their speed to their visual performance when driving at night.

Although these observations were made for only four drivers, other studies which show that street lighting potentially induces higher speeds were reported also by Assum et al., (1999) and Jägerbrand & Sjöbergh (2016). Assum, Bjørnskau, Fosser, & Sagberg (1999) investigated the association between roadway lighting and speed behaviour and theorised that drivers would not adjust their speed behaviour following the installation of street lighting. Their hypothesis yielded contrary results with the highest speed occurring during night time on roads with street lighting. Subsequent investigations were undertaken by Jägerbrand & Sjöbergh (2016) who reported similar trends. Analysing speed differences at night under different weather conditions on roads with street lighting and without street lighting, these authors found that in adverse weather conditions, greater decrements in speed were more common on roads without overhead lighting than on roads with overhead lighting indicating that the drivers do not adjust their speeding behaviour significantly on roads with street lighting even in poor visibility conditions.

5.3.2 Intersection Behaviour

For all the intersections analysed, the approach speed of the novice drivers were consistently higher than the approach speeds of the experienced drivers. For both novice and experienced drivers, average speeds were higher when approaching a green traffic signal and an amber traffic signal. Intersection approach speed was also analysed under different lighting conditions to determine whether drivers adjust their speed at intersections when no street lighting is present. The results show that the approach speed adopted at unlit intersections is comparable to the approach speed at lit intersections.

Since speed contributes to crash severity, lowering speed on approach to intersections can promote safety and can be regarded as a measure of hazard perception. Adopting lower intersection approach speeds help drivers scan the intersection and traffic environment to a greater extent and provide them with sufficient time to enact evasive manoeuvres if hazards are present. Consequently, a greater adjustment in speed behaviour is warranted to recognise and react to hazards in time at unlit intersections. Given that non-illuminated intersections degrade the ability to recognize other vehicles and pedestrians in the intersection to a much greater extent than illuminated intersections do, it was surprising that intersection approach speeds at unlit intersections were similar to intersection approach speeds at lit intersections. This marginal difference in intersection approach speed by both the novice and experienced drivers in this study can be accounted for by two reasons. Firstly, the slight adjustment in speed behaviour at unlit intersections on the part of these drivers may be an indication of these drivers' failure to acknowledge the need to compensate for visual losses at night by decreasing speed. Secondly, the lack of speed adjustment at non-illuminated intersections may be owing to the fact that at poorly lit intersections these drivers did not recognize that an intersection is being approached and consequently did not reduce their speed earlier on.

In terms of gaze behaviour, when compared to the novice drivers, the experienced drivers generally demonstrate a higher proportion of glances and a longer duration of glances at intersections. Overall, the novice drivers tend to primarily allocate visual attention to certain regions of an intersection while neglecting others. Fixations appear to be directed toward the direction of travel and the future path of the vehicle (straight/right/left). The frequency of mirror-checking tended to be minimal for the novice drivers. These results indicate that the novice drivers adopted a narrower and horizontal scanning pattern which is exclusively focussed on the direction of travel (Bao & Ng Boyle, 2009). The novice drivers also demonstrated a higher tendency to spend more time carrying out short and rapid scans in the different directions and less time scrutinising the regions of visual interest. This visual search strategy can become problematic at night time where more time needs to be allocated to gazing glance locations since visibility is compromised and drivers need more time to recognise hazards.

The experienced drivers also spent a large amount of time directing their gaze forward and toward the direction of travel. Greater visual attention was also allocated to mirror-checking among these drivers. Checking the mirrors allowed the driver to observe what is happening around the vehicle and aided in obtaining a wider field of vision and perspective of the traffic situation at intersections. The higher propensity among the experienced drivers to check the mirrors indicate that the experienced drivers adopted a broader visual scanning pattern (Bao & Ng Boyle, 2009). The frequency of glances is generally similar to or typically higher than the duration of glances which indicates that the experienced drivers also spend less time scrutinising glance directions, although this may occur to a lesser extent than it does for the novice drivers.

Gaze behaviour at illuminated and non-illuminated intersections was also analysed for the novice and the experienced drivers. The results show that the average glance frequency and average glance duration changes as the lighting at intersections vary. At illuminated intersections the novice and the experienced drivers have a higher frequency of glances but a higher duration of glances at non-illuminated intersections. These results indicate that at unlit intersections, drivers spend more time gazing or scanning a particular direction. This may be attributed to the lack of lighting which makes it difficult to see. Consequently, the mental task load is greater (Oya *et al.*, 2002) and drivers have to spend more times scanning a particular direction to retrieve information about vehicle or pedestrian movements within the intersection.

5.4 Night Driving Survey

This section discusses the main findings about drivers' behaviour, experience and perceptions of night driving. In terms of enjoying driving at night, more young male drivers indicated that they enjoy driving at night. This finding may explain why a greater proportion of young male drivers are involved in traffic crashes and fatalities at night- they tend to drive more at night as they enjoy driving at night. Elderly drivers and female drivers reported lower levels of driving enjoyment at night. This may be a contributing factor in the low fatality rates reported for these groups of drivers. Their lower fatality rates may be owing to lower exposure since they do not enjoy driving at night. The lower levels of driving enjoyment at night for elderly drivers may also be symptomatic of risk awareness and a greater awareness of visual challenges experienced at night.

Ability to drive safely at night was also generally rated more positively by young and middle-age drivers. Male drivers also rated their driving ability at night more highly than female drivers. These results indicate that for most drivers driving at night is an enjoyable experience and one that is not fraught with many difficulties. These findings are somewhat surprising given that higher traffic crashes occur at night and that driver's ability to drive safely is compromised by poor visibility, poor vision and generally an increase in fatigue. The positive rating of driving ability at night is indicative of the fact that drivers feel confident in their driving abilities at night. This confidence may be derived from lack of awareness of the risks associated with night time driving or a high level of self-efficacy to be able to overcome these difficulties. A higher proportion of elderly drivers rated their ability to drive safely at night more negatively. This negative self-appraisal of driving skills at night may stem from greater awareness of driving limitations at night. Compared to other middle-age and young drivers, elderly drivers are more likely to be informed and aware about the reduced sensori-perceptual and visual limitations at night which would be translate into decreased confidence in their driving ability at night.

When analysing risk perception at night according to crash concerns, elderly drivers showed the most concern for being involved in a crash during night time. This demonstrates higher risk perception at night among these drivers. Conversely, young drivers showed the most concern for having being involved in a crash during daytime which demonstrates lower risk perception at night time. In terms of the greatest concern about being involved in a crash at night time, elderly drivers' concern was primarily based on vision or visibility related issues. This indicates that these drivers are more vulnerable to visual deficits and have a greater appreciation for visibility issues at night. To a lesser extent, visibility related issues were also primary concerns for middle-age drivers. Conversely, young drivers' concerns were predominantly based on external factors that threaten safety such as other drunk or reckless drivers and being a victim of crime.

When comparing driving behaviour at night, 32% of drivers that they have driven at night when they think they have exceeded the legal blood-alcohol limit. This proportion of drivers may be higher in reality since drivers may not be aware that they engage in drink driving while others may not have indicated that they engage in this behaviour due to the effects of social desirability. Surprisingly, less than half of all drivers believe that it takes them longer to see and react to objects in the roadway at night, despite literature pointing to the contrary. This contrary finding may be due to overconfidence in driving ability in general or particularly at night. Alternatively, given that roadway objects (such as signs, road markings, road furniture) have oftentimes been engineered to be retroreflective, drivers may also feel more confident at seeing objects at night even though these objects have to some extent been illuminated.

More drivers indicated that they use their seat belts more frequently at night time compared to daytime, which can be taken as a surrogate safety measure that indicates greater perception of risk at night. Interestingly, a smaller proportion of drivers reported feeling tense while driving at night while a higher proportion of drivers reported being afraid while driving at night. The absence of tenseness while driving at night indicates that the majority of drivers are comfortable with night driving. The feelings of fear while driving at night can primarily be attributed to fear of being a victim of crime as criminal activity on the roads in terms of hijacking is known to prevalent at night on South African roads. Finally, compared to daytime a high proportion of drivers indicated that they adopt higher speeds at night time but lower speeds during daytime. The difference in speed behaviour is most likely due to the effect of traffic volumes, since the presence of traffic inhibits speed and forces drivers to drive more slowly.

In terms of speeding at night, young male drivers showed a greater propensity for speeding at night. Middle-age drivers showed medium propensity to speed and elderly drivers showed the lowest propensity to speed at night. The motivations cited as most influential in the decision to speed at night was the lack of law enforcement on the roads at night and high self-efficacy levels in being able to respond to hazard in time. These results show that speeding at night is motivated by overconfidence in driving ability at night.

In terms of fatigue at night, almost half of drivers reported that they drive while tired at night. Generally, elderly drivers reported lower levels of fatigue at night. Young and elderly drivers respectively experienced greater levels of fatigue at night. While a smaller proportion of drivers indicated that they experience lapses in concentration at night almost half of all drivers reported that they experience highway hypnosis at night. In terms of age, surprisingly young drivers showed the highest propensity for highway hypnosis followed by middle-age drivers and young drivers. Interestingly, the countermeasures most frequently adopted to counteract the feelings imply that the driver continues to drive.

Driving violations and aberrant were also evaluated at night. The overwhelming majority of drivers indicated that they do not drive too fast for the driving conditions. More drivers deliberately drive above the speed limit on freeways compared to urban and residential roads. Disregarding traffic control signs were also committed more frequently at night. Errors in depth and speed perception were also frequent at night. With regards to speed estimation, more than half of all drivers indicated that they sometimes misjudge the speed of oncoming vehicles while overtaking. With regards to depth perception, almost half of all drivers indicated that they occasionally misjudge gaps when entering main road traffic. With regards to pedestrian detection at night, a higher proportion of drivers indicated that they do not see pedestrians crossing when turning onto a new road while a smaller proportion of drivers indicated that they do not see pedestrians at designated crosswalks.

While most drivers indicated that they would use high beams when travelling on a straight, rural road with very little street lighting and less traffic, a slightly higher proportion of drivers indicated that they would us low beams (this number was slightly lower than 50% of drivers). Male drivers showed a greater propensity to using low beams. In terms of the reasons for using low beams, most drivers reported that the inconvenience or fear of forgetting to switch back to back to high beams was the main reason they tended to use or would use low beams for the majority of the time. These findings correspond with those obtained by Fekety et al. (2013) in their study on the reasons behind drivers' underuse of high beams at night. The findings indicate that a slightly higher proportion of the driver population underuse their high beams which is a significant visibility aid at night time. This may in part account for traffic crashes at night, especially crashes with pedestrians who tend to be darkly clad.

Drivers' difficulty with certain driving tasks at night was also investigated. The most challenging task at night for drivers was managing headlight glare from oncoming cars. With regards to depth perception, more than half of all drivers reported difficulties in judging the distance between their own vehicle and the vehicle ahead of them. In terms of speed perception at night, almost half of all drivers indicated that they find it difficult to determine whether the vehicle in front of them is speeding up or slowing down. With regards to peripheral vision, more than half of all drivers indicated that they find it challenging to see pedestrians in their peripheral view. This finding is expected since darkness drastically reduces peripheral vision which makes it more challenging for drivers to see pedestrians emerging from the side.

Chapter 6: Conclusions and Recommendations

6.1 Introduction

This chapter provides a summary of the key findings with reference to the aims and objectives, the limitations of the study and recommendations.

6.2 Key findings of the study

This section presents the key findings from this study and these are presented with reference to the research objectives stated earlier in the study. The main findings of the study are summarised below:

The central aim of this study was to explore driver performance and behaviour under night time conditions. Within this framework, the specific objective used to answer the main research problem is described below.

i. **Research objective 1**: To investigate the frequency and characteristics of night time traffic crashes and fatalities.

Data on road traffic crashes and fatalities were analysed to determine the frequency of traffic crashes and fatalities and the characteristics of night time crashes and fatalities in terms of daily and hourly trends, crash types and the demographic factors (gender, age, and race) of the road users commonly involved in traffic fatalities at night time.

The results are summarised in Chapter 4 and discussed in Chapter 5. The results indicate that road traffic crashes significantly decrease at night while road traffic fatalities slightly increase at night. The higher fatal crash involvement rates at night is evidence that night time conditions pose a greater danger to road users. During night time hours, both RTCs and RTFs occur more frequently during the weekend (Saturday and Sunday, respectively) compared to weekdays. In terms of hourly trends, most RTCs occur at 05:00 PM, 04:00 PM and 07:00 AM, respectively while most RTFs occur at 08:00 PM, 07:00 PM and 09:00 PM, respectively. In terms of crashes at night, the most common crash at night are crashes with fixed/other object which are prevalent throughout the early evening period and continue to dominate at midnight and the early morning period.

With regards to road users, pedestrians comprised the largest proportion of fatal crashes followed by drivers, passengers and cyclists. Compared to daytime, fatalities for both males and females increase, with male drivers demonstrating the greatest increase fatalities. In terms of age, only young and middle-age drivers had higher fatalities. Traffic fatalities were predominantly higher at night for both young males and young females compared to middle-age drivers, with young males showing the highest fatality frequency. While fatalities at night were higher relative to daytime for drivers from all racial groups, coloured and black drivers had a higher number of traffic deaths. For non-motorised road users, male pedestrians have substantially higher fatalities relative to female pedestrians at night time. In terms of age, higher traffic fatalities during night time were only observed for young and middle-age pedestrians. Traffic fatalities were predominantly higher at night for both young males and young and middle-age males and females. While fatalities at night were higher relative to daytime for pedestrians from all racial groups, coloured and black pedestrians had a higher number of traffic deaths.

The data obtained from road traffic crashes and fatalities datasets were analysed and the results are summarised in Chapter 4 and Chapter 5. This research objective has therefore been addressed.

ii. **Research objective 2**: To investigate driver speed choice at night time.

Although the sample size of drivers for the naturalistic driving videos was small, it was observed that at night time all four drivers adopted higher speed than daytime on freeways and rural roads. While the novice drivers adopted speeds higher than the speed limit, the experienced drivers adopted speed that closely approximates the speed limit. Hence, the drivers observed in this study do not adopt lower speed at night time. Roadway lighting also had an effect on the drivers speed. When passing through illuminated street sections on rural roads, all four drivers increased their speed and once they exited the illuminated road section a reduction in speed was observed. Drivers' speed behaviour at night time is presented in Chapter 4 and discussed in Chapter 5. This research objective has therefore been achieved.

iii. **Research objective 3**: To investigate driver gaze behaviour at various intersections at night time

Gaze behaviour at intersections was analysed for the novice and experienced drivers during straight-through, right and left hand turn driving manoeuvres. Glance frequency and duration to the left, right, far left, far right, rear view mirror and side mirrors were recorded and analysed to ascertain drivers visual search strategy at night. When compared to novice drivers, experienced drivers demonstrate a higher proportion of glances and a longer duration of glances at intersections. Novice drivers demonstrate a higher tendency to spend more time carrying out short and rapid scans in the different directions and less time scrutinising the regions of visual interest. The results show that the two novice drivers in this study adopt a narrower and horizontal scanning pattern which is primarily focussed on the direction of travel. Experienced drivers also spend a large amount of time directing their gaze forward and toward the direction of travel. Greater visual attention is also allocated to mirror-checking among these drivers. The higher propensity among experienced drivers to check the mirrors indicate that experienced drivers tend to adopt a broader visual scanning pattern. The results are presented in Chapter 4 and discussed in chapter 5. This research objective has therefore been addressed.

iv. **Research objective 4**: To investigate drivers' behaviour and perceptions of night driving.

Driver behaviour and perceptions of night driving in terms of speed behaviour, traffic violations, fatigue, vehicle headlight usage, perceptions and task difficulty were investigated by means of a night driving survey. Overall, young male drivers show lower risk perception at night compared to elderly drivers. Young and middle-age drivers were also more likely to rate their driving ability at night more highly than elderly drivers. Young, male drivers were more likely to engage in speeding behaviour and traffic violations at night. Unexpectedly, fatigue at night was more pronounced among young and middle-age drivers and these drivers also reported a higher frequency of experiencing highway hypnosis at night. With regards to task difficulty at night, speed estimation, depth perception, peripheral vision and pedestrian detection were more challenging for all drivers. Drivers' perceptions and behaviour at night time was analysed and the results are presented in Chapter 4 and 5. This objective has therefore been achieved.

6.3 Limitations of the study

This research is subject to several limitations. Firstly, the results from the naturalistic driving study are limited since the sample size is small and not representative of the driving population. The results obtained may therefore not be generalizable to all drivers. Secondly, omissions in reporting crucial details in crash information that help explain crashes and fatalities at night such as alcohol level, visibility conditions or fatigue is also problematic. Without this level of detail, it is difficult to narrow down the definitive causes for the crashes and fatalities observed in this study.

6.4 Considerations for future research

Based on the delineations and limitations highlighted in this study, the following research directions for further study on night time traffic crashes and fatalities are proposed:

1. Since the data from the naturalistic driving videos were based on a small sample, additional research studies need to be taken with a larger and more representative sample to ascertain whether the results obtained in this study is representative for all drivers. This research should preferably also examine driving behaviour at day and night time to examine the influence of darkness on driving behaviour.

2. In an effort to gain a richer understanding of the factors that influence crashes at night time, additional and thorough research is needed into the human factors contributing to crashes and fatalities at night time. These factors could not be addressed in this study but include, for example, fatigue, alcohol consumption and social-psychological determinants that drive unsafe driving behaviour at night.

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Appendices

Appendix A

DRIVING BEHAVIOUR AT NIGHT TIME

QUESTIONNAIRE

Please complete the following questionnaire by either ticking one of the boxes or writing in the space provided.

TO START WITH, A FEW QUESTIONS ABOUT YOUR DRIVING HISTORY

1. Are you male or female?

- ☐ Male
- ☐ Female

2. How old are you?

- ☐ 18-30 years old
- ☐ 31-64 years old
- ☐ 65 years and older

3. Do you currently hold a license to drive a motor vehicle?

- ☐ Yes
- ☐ No

4. How long have you held a driver's license?

- ☐ 0-6 months
- ☐ 6-18 months
- ☐ 1.5 -2 years
- ☐ 3-5 years
- ☐ 5-10 years
- ☐ 10-20 years
- ☐ More than 20 years

5. Approximately how many kilometres do you drive per year?

- ☐ < 15 000 km
- ☐ 15 000 km-30 000 km
- ☐ > 30 000 km

6. In the past month, how often did you drive at night <u>during the week</u> (Monday-Friday)?

- ☐ None
- ☐ A few times per month, but not once a week
- ☐ At least once a week
- ☐ Approximately 2-3 times per week
- ☐ Almost everyday

7. In the past month, how often did you drive at night <u>during the weekend</u> (Saturday-Sunday)?

- ☐ None
- ☐ A few times per month, but not every weekend
- ☐ At least once a weekend, but not on Saturday and Sunday
- ☐ On both Saturday and Sunday

8. How often do you travel on the following roads at night?

	Never	Rarely	Sometimes	Often	Always
Freeways	☐	☐	☐	☐	☐
Rural roads	☐	☐	☐	☐	☐
Urban roads/ residential roads	☐	☐	☐	☐	☐

NOW SOME GENERAL QUESTIONS ABOUT YOUR EXPERIENCE OF DRIVING AT NIGHT

9. Do you enjoy driving at night?

- ☐ Not at all
- ☐ Not really
- ☐ Neutral
- ☐ Somewhat
- ☐ Very much

10. How would you rate your ability to drive safely at night?

- ☐ Poor
- ☐ Fair

- ☐ Good
- ☐ Very good
- ☐ Excellent

11. Do you have more concerns about being involved in an accident at night compared to during the day?

- ☐ Yes, more concern at night
- ☐ No, more concern during the day
- ☐ Same amount of concern for both day and night time

12. Among the concerns that you have about having an accident at night, what are your concerns? Even if you selected 'no', answer the question according to which concerns would be most important to you if you were to choose 'yes'. Rank each of the following items in order of importance from 1-10, with #1 being the most important concern and #10 being the least important concern. Enter the number in the space provided.

Difficulty seeing because of eye-sight related problems	☐
Lack of visibility due to low lighting	☐
Not seeing unexpected hazards such as dangerous objects	☐
Not seeing unexpected pedestrians	☐
Not seeing animals	☐
Lack of visibility due to adverse weather	☐
Other reckless or drunk drivers	☐
Not getting help if I had an accident	☐
Being a victim of crime	☐
Not seeing road signs, traffic lights and road markings	☐

13. If there are any other concerns that you may have, that are not listed above, please state it here: :

____

14. Compared to driving during the daytime, how often do you do each of the following while driving at night?

	More during day	About the same frequency at day and night	More at night	Neither at day or night
I choose a speed that is lower than the speed limit	☐	☐	☐	☐
I choose a speed that is higher than the speed limit	☐	☐	☐	☐
I spend more time scanning for hazards	☐	☐	☐	☐
I use my mobile phone	☐	☐	☐	☐
I am more aware and observant for animals/other obstacles	☐	☐	☐	☐
I leave more space between my car and the car I am following	☐	☐	☐	☐
I am likely to drive in the rain/fog	☐	☐	☐	☐
I wait for bigger gaps when turning into traffic	☐	☐	☐	☐
I drive if I am feeling sleepy and struggle to keep my eyes open	☐	☐	☐	☐
I avoid roads/areas that are unsafe	☐	☐	☐	☐
I feel more tense when driving	☐	☐	☐	☐
I feel more afraid when driving	☐	☐	☐	☐
I use my seatbelt	☐	☐	☐	☐
I intentionally enter an intersection after the traffic light has turned red	☐	☐	☐	☐
I spend more time deciding when to take a gap when making a right turn at an intersection	☐	☐	☐	☐
It takes me longer to see and react to objects in the road	☐	☐	☐	☐

I drive when I think I am over the legal blood-alcohol limit	☐	☐	☐	☐

15. How often, when given the opportunity, would you say you speed at night?

- ☐ Never
- ☐ Rarely
- ☐ Sometimes
- ☐ Often
- ☐ Always

16. On those occasions when you find yourself speeding at night, how likely is it that it would be for each of the following reasons? Even if you do not speed at night, answer the question according to which reasons would be most appealing to you.

	Extremely unlikely	Unlikely	Neither likely nor unlikely	Likely	Extremely likely
You don’t know what the speed limit is	☐	☐	☐	☐	☐
You are unaware of your speed	☐	☐	☐	☐	☐
You enjoy speeding	☐	☐	☐	☐	☐
You deliberately set your own safe speed which is higher than the speed limit	☐	☐	☐	☐	☐
You are in a hurry	☐	☐	☐	☐	☐
You think that the speed you have chosen is appropriate for the driving conditions	☐	☐	☐	☐	☐
You are confident in your ability to stop in time for unexpected pedestrians/ obstacles and other motorists	☐	☐	☐	☐	☐
You think there is no danger in driving faster than the speed limit because there is less traffic on the road	☐	☐	☐	☐	☐
You don’t think you will be detected by a speed camera	☐	☐	☐	☐	☐

You don't think there are any police/traffic officers on the road that you are driving on	☐	☐	☐	☐	☐

17. If there are any other reasons that you may have, that are not listed above, please state it here::

____

18. How often do you drive in the early morning (5 AM- 7 AM)?

- ☐ Never
- ☐ Rarely
- ☐ Sometimes
- ☐ Often
- ☐ Always

19. How often do you drive during the post-lunch period during the day (2 PM-3PM)?

- ☐ Never
- ☐ Rarely
- ☐ Sometimes
- ☐ Often
- ☐ Always

20. The following questions deal with your experience of feeling tired and/or sleepy at night. Answer all questions in terms of how often you do the following things while driving at night.

	Never	Rarely	Sometimes	Often	Always
Drive while you are tired	☐	☐	☐	☐	☐
Have fallen asleep or nodded off (even if only for a brief moment)	☐	☐	☐	☐	☐
Struggle to keep your eyes open	☐	☐	☐	☐	☐
Realise you have no clear recollection of the road along which you have just been travelling	☐	☐	☐	☐	☐
Have lapses of concentration or struggle to focus on the road	☐	☐	☐	☐	☐

21. If you do feel sleepy while driving, what do you do?

- ☐ I continue driving and open a window
- ☐ I pull over and take a nap

- ☐ I get coffee or another caffeinated drink and continue driving
- ☐ I get out/ stretch/exercise
- ☐ I continue driving and turn on the radio
- ☐ I change drivers
- ☐ Other

Please state the reason if you have chosen 'other'

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22. How often do you do each of the following while driving at night?

	Never	Rarely	Sometimes	Often	Always
Drive too fast for the driving conditions	☐	☐	☐	☐	☐
Fail to notice that pedestrians are crossing when turning onto a new road	☐	☐	☐	☐	☐
Disregard stop signs	☐	☐	☐	☐	☐
Knowingly exceed the 60 km/h speed limit in a built up area	☐	☐	☐	☐	☐
Knowingly exceed the 120 km/h speed limit on freeways	☐	☐	☐	☐	☐
Have to break sharply to avoid an accident with the vehicle ahead of you because it has slowed	☐	☐	☐	☐	☐
Misjudge the speed of an oncoming car when overtaking	☐	☐	☐	☐	☐
Fail to notice someone waiting to cross at a pedestrian crossing until it's too late to stop	☐	☐	☐	☐	☐
Misjudge the gaps when entering the main road traffic	☐	☐	☐	☐	☐
Find you are travelling too fast to negotiate a bend safely when cornering, and have to brake sharply	☐	☐	☐	☐	☐
Have to brake or swerve suddenly to avoid an accident	☐	☐	☐	☐	☐

Avoid routes that require you to make a right turn at busy intersections	☐	☐	☐	☐	☐
Forget to activate your car's headlights	☐	☐	☐	☐	☐

Consider the following scenario when answering the next two questions. You are driving on a straight, rural road with a few slight bends, little or no street lighting and little traffic in the oncoming lane at night?

23. Which beam setting on your car's headlights would you prefer to use for the majority of the drive?

- ☐ Low beams
- ☐ High beams

24. What are some of the reasons you would prefer to use low beams for the majority of the drive instead of high beams? Even if you chose 'high beams' as your preference, please answer the question according to which reasons would be most appealing if you were to choose 'low beams'. Rank each of the following reasons in order of importance from 1-5, with #1 being the most important reason and #5 being the least important reason. Enter the number in the space provided.

I get tired of switching between high beams and low beams	☐
I am afraid that I might forget to switch back to low beams and that the glare from the high beams may obstruct the view of oncoming drivers and cause an accident	☐
I can see better with low beams than high beams	☐
I forget to activate my high beams after cars have passed	☐
There is little or no difference in the visibility distance offered by low beams and high beams	☐

25. If there are any other reasons that you may have, that are not listed above, please state it here::

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26. How difficult or easy is it for you to complete the following tasks while driving at night?

	Very difficult	Somewhat difficult	Neutral	Somewhat easy	Very easy
Seeing pedestrians crossing from the side until they are right in front of you	☐	☐	☐	☐	☐
Seeing cars moving from the side until they are right in your field of view	☐	☐	☐	☐	☐
Seeing the road when oncoming cars approach you with their high beams activated	☐	☐	☐	☐	☐
Noticing when the car in front of you is speeding up or slowing down	☐	☐	☐	☐	☐
Determining what the appropriate speed is for the conditions in which you are driving	☐	☐	☐	☐	☐
Judging the distance between your car and other moving cars	☐	☐	☐	☐	☐
Judging how close or far pedestrians are from you	☐	☐	☐	☐	☐

27. Is there anything else that you would like to contribute that may shed some more light on your experience of driving at night?

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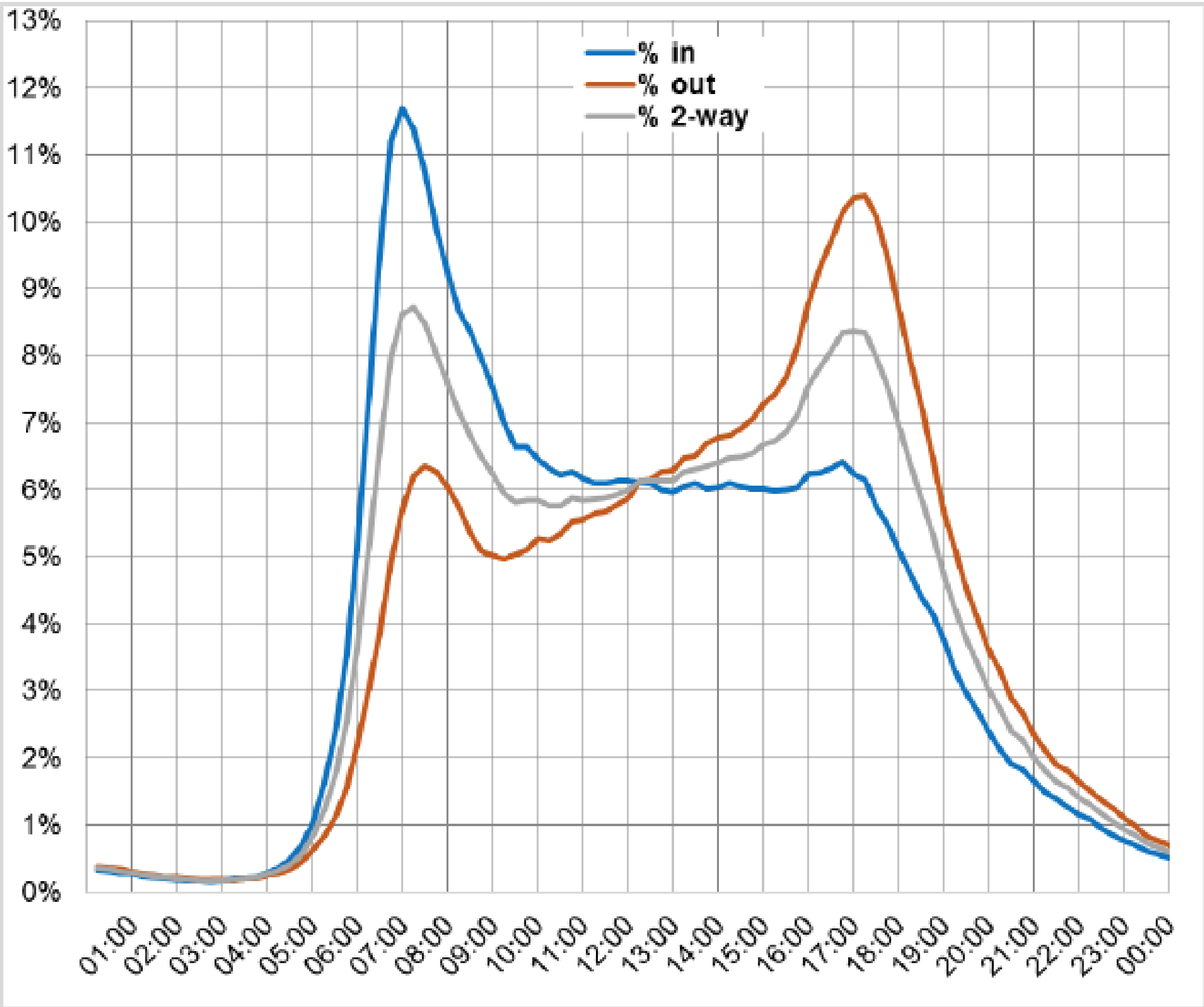
THANK YOU FOR YOUR PARTICIPATION!

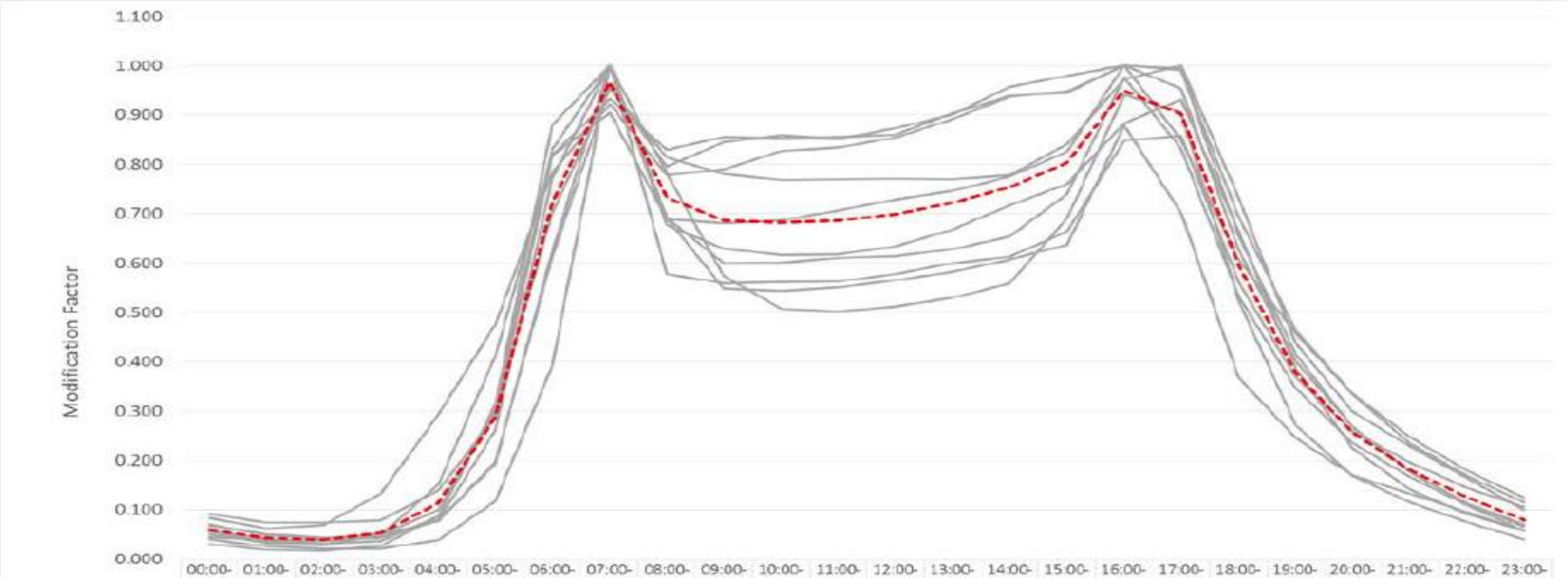
Appendix B

Hourly traffic flow variation as a % of ADT on major roads in Johannesburg, South Africa (Sampson, 2017)



Appendix C

Hourly traffic pattern over typical weekday (De Jongh & Bruwer, 2017)



	00:00-01:00	01:00-02:00	02:00-03:00	03:00-04:00	04:00-05:00	05:00-06:00	06:00-07:00	07:00-08:00	08:00-09:00	09:00-10:00	10:00-11:00	11:00-12:00
Cape Town	0.070	0.048	0.042	0.050	0.100	0.297	0.702	0.954	0.814	0.780	0.769	0.770
Port Elizabeth	0.040	0.026	0.021	0.021	0.038	0.118	0.391	1.000	0.691	0.548	0.544	0.551
Bloemfontein	0.068	0.051	0.043	0.047	0.077	0.193	0.624	1.000	0.577	0.559	0.561	0.563
Durban	0.044	0.039	0.032	0.036	0.087	0.304	0.831	1.000	0.693	0.600	0.601	0.611
Kimberley	0.092	0.074	0.074	0.079	0.140	0.289	0.818	0.932	0.829	0.856	0.853	0.856
Pretoria	0.031	0.019	0.017	0.027	0.085	0.313	0.880	1.000	0.783	0.574	0.507	0.502
Emalahleni	0.051	0.032	0.031	0.048	0.152	0.412	0.817	0.904	0.689	0.681	0.687	0.706
Potchefstroom	0.083	0.062	0.069	0.132	0.293	0.476	0.784	0.922	0.778	0.790	0.827	0.834
Polokwane	0.057	0.041	0.038	0.044	0.078	0.261	0.772	1.000	0.677	0.629	0.616	0.618
Vryburg	0.056	0.035	0.028	0.049	0.077	0.197	0.613	0.958	0.796	0.845	0.859	0.852
RSA	0.059	0.043	0.040	0.053	0.113	0.286	0.723	0.967	0.733	0.686	0.682	0.686

	12:00-13:00	13:00-14:00	14:00-15:00	15:00-16:00	16:00-17:00	17:00-18:00	18:00-19:00	19:00-20:00	20:00-21:00	21:00-22:00	22:00-23:00	23:00-00:00
Cape Town	0.771	0.770	0.778	0.842	0.972	1.000	0.732	0.439	0.299	0.228	0.164	0.100
Port Elizabeth	0.565	0.583	0.607	0.637	0.878	0.702	0.368	0.245	0.170	0.133	0.096	0.057
Bloemfontein	0.578	0.599	0.613	0.664	0.849	0.858	0.562	0.369	0.260	0.196	0.145	0.106
Durban	0.614	0.627	0.654	0.741	0.976	0.832	0.534	0.346	0.235	0.167	0.109	0.058
Kimberley	0.860	0.904	0.939	0.945	1.000	0.991	0.694	0.464	0.335	0.247	0.179	0.125
Pretoria	0.512	0.530	0.559	0.691	0.941	0.906	0.523	0.271	0.169	0.114	0.075	0.040
Emalahleni	0.729	0.746	0.776	0.826	1.000	0.953	0.627	0.402	0.268	0.178	0.113	0.066
Potchefstroom	0.854	0.891	0.937	0.948	1.000	0.850	0.607	0.458	0.334	0.234	0.168	0.115
Polokwane	0.634	0.667	0.717	0.761	0.884	0.931	0.664	0.385	0.225	0.141	0.091	0.057
Vryburg	0.873	0.901	0.958	0.979	1.000	0.993	0.655	0.415	0.268	0.176	0.113	0.070
RSA	0.699	0.722	0.754	0.803	0.950	0.902	0.597	0.380	0.256	0.181	0.125	0.079