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Motorcycle safety after-dark: The factors associated with greater risk of road-traffic collisions

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Supplementary Files:
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Abstract

The effect of ambient light level on road traffic collisions (RTCs) involving a motorcycle was investigated. Data were drawn from the STATS19 database of UK reported RTCs for the period 2005 to 2015. To isolate the effect of ambient light (daylight vs darkness) an odds ratio was used to compare RTCs at specific times of day in the weeks either side of the Spring and Autumn clock changes. This work extended previous studies by using a more precise method for distinguishing between RTCs in daylight and after dark, thus avoiding the ambiguity of twilight. Data for four-wheel motor vehicle (FWMV) RTCs were also investigated to provide a datum. As expected, the risk of an RTC occurring was significantly higher after dark compared to daylight for both motorcycles and FWMVs. Investigation of contextual factors suggests that risk after dark is significantly higher for motorcycles compared to FWMVs for RTCs with two-vehicles, on roads with low speed limits (≤30 mph), at T-junctions, and junctions controlled by a give way sign. These are the situations where visual aids for increasing conspicuity after dark have the greater potential for reducing motorcycle RTCs.

1. Introduction

Motorcyclists are classified as vulnerable road users as they are involved in a disproportionate number of road traffic collisions (RTCs) given the distance travelled (Robbins et al., 2019). In 2018, there were 17,890 reported motorcycle RTCs in the UK of which there were 354 motorcyclist fatalities, this being 20% of all road deaths in that year (DfT, 2019a, 2019b). A motorcycle RTC is any RTC involving a motorcycle.

Clarke et al. (2007) studied motorcycle RTCs, recorded by police forces in the midlands area of the UK, over the years 1997 to 2002. The sample contained a mix of urban, suburban and rural road types, with speed limits of between 20 and 70mph. Of the 1790 RTCs recorded, right-of-way (ROW) RTCs were the most frequent (38%), ahead of other common types such as losing control on bends (15%) and motorcycles maneuvering around other vehicles (17%). ROW RTCs occur when a road user pulls out of the side road at a junction into the path of another vehicle on the main carriageway, and claims to have not seen the oncoming vehicle (Clarke et al., 2007) - commonly termed “looked but fail to see” (LBFTS) errors (Brown, 2002).

One possible reason for LBFTS errors is poor conspicuity. Conspicuity is the combined effects of visibility (perceptual conspicuity) and expectation (cognitive conspicuity). Adapting the pedestrian-focused definitions of Tyrrell et al. (2016) a motorcyclist is visible when seen by a driver who has reason to expect a motorcyclist to be present; a motorcyclist is conspicuous when recognised by a driver who had no advance warning or expectation of encountering a motorcyclist. In other words, a conspicuous motorcycle is an object which is easily detected and identified as a motorcycle when the observer did not expect to see a motorcycle. Visual responses are impaired after dark due to the lower light level (Plainis et al., 2005), which reduces the visual component of conspicuity. Visibility is a function of the contrast of an object against its background and its size (the angle it subtends at the eye of the observer). The Relative Visual Performance model shows the reduction in visual performance (e.g. reaction time) with objects of smaller contrast and size (Rea & Oullette, 1991). The ability to discriminate detail according to size is known as visual acuity. Reductions in visual acuity and contrast sensitivity after dark are mitigated to some extent by road lighting, but for cost-effective use it is installed only where it is predicted to be of benefit. Motorised vehicles including motorcycles are also required to use headlights after dark, mandated in the UK by the Highway Code (DfT, 2020).

Of 1,003,665 motorcycle RTCs reported by two national traffic databases in the USA between 1992 and 2004, 26% occurred after dark, with those resulting in 43% of all RTC fatalities (Samaha et al., 2007). After dark, the fatality rate per crash was higher for unlit roads (5.2%) than for lit roads (3.8%), although the data reported do not reveal if that is a significant and practical increase. The sample also included roads with a range of speed limits, which were not controlled for when comparing unlit and lit roads.

Table 1 shows nine studies which investigated the effect of ambient light level (amongst other factors) on motorcycle RTCs. These studies used data reported by the police at the scene of the RTC, such as STATS19 in the UK, which documents whether a crash occurred after dark or in daylight. The data represent four countries (Australia, Malaysia, UK and USA).

These studies tend to compare RTC frequencies in daylight and darkness, as these give a large and natural variation in the amount of light and should reveal the effect, if any, of ambient light level. One confound to such analysis is the degree to which twilight is accounted for. Twilight is the partially daylit period immediately before sunrise and immediately after sunset. Daylight persists in twilight due to the reflection and scattering of sunlight towards the horizon of a terrestrial observer and thus the twilight periods are not fully daylit nor dark but a gradual transition between the two (Muneer, 1997). Analyses of RTCs occurring in twilight introduce ambiguity as to the effect, if any, of ambient light. Civil twilight is defined as having sufficient daylight illuminance to enable outdoor civil activity to continue unhindered without resorting to the use of electric road lighting, and is the period where solar altitude is between 0° and -6° (Muneer, 1997). Therefore, for RTC analyses, daylight may be defined as a solar altitude above 0° and darkness as a solar altitude less than -6°. Definitions in past studies, however, are not always so precise. As can be seen in Table 1, previous studies do not give specific definitions of darkness and daylight, with the majority of the classifications being attributed by the police officer attending the scene of the RTC. Of the nine studies in Table 1, seven concluded that darkness is associated with greater injury severity compared to daylight conditions. This conclusion is supported by Lin et al. (2003) who administered a questionnaire to students from two residential areas in Taiwan between 1994 and 1996 following their involvement in a motorcycle RTC. Lighting conditions at the time of the RTC were categorised as either daylight, twilight or dark and the analysis used odds ratios to determine injury risk. They concluded that darkness was associated with a greater level of injury severity compared to daylight.

While these studies investigated RTC severity after dark, only one (Cercarelli et al., 1992) investigated RTC risk, specifically comparing the risk of motorcycle-car and car-car RTCs after dark. They found no difference in RTC risk between daytime and after dark.

The ROW RTC, the most frequent type of motorcycle crash in the UK, occurs when a road user pulls out of the side road at a junction into the path of an oncoming motorcycle (Clarke et al., 2007). Four studies have investigated the effect of darkness on RTCs at junctions. Pai and Saleh (2007) investigated the effect of junction control measures such as stop signs, give way signs, uncontrolled junctions and signal controlled junctions (e.g. traffic lights) on motorcycle RTCs. They found that, after dark, motorcyclists were more likely to be severely injured at stop and give way junctions, but not signal controlled junctions.

Pai (2009) extended these findings by concluding that a motorcyclist's ROW is more likely to be violated at stop/give way-controlled junctions at dark compared to daylight. However, while Pai and Saleh (2007) used the categorisations of daylight and darkness as reported by police officers in the STATS 19 database for UK crashes, Pai (2009) grouped RTCs by the time of the collision, by comparing early morning (00:00-06:59) and evening (18:00-23:59) to daylight (09:00-15:59).

Two further studies investigated the effect of darkness on RTCs at junctions but did not specifically focus on motorcycles. Bullough et al. (2013) investigated the effect of road lighting on RTC severity at junctions in Minnesota, USA, and found that lit junctions were associated with a 12% lower night/day crash ratio than unlit junctions. Chen, Cao and Logan (2012) investigated RTCs in Victoria, Australia for the period 2000 to 2009, and found that one of the most influential factors on crash severity at junctions was time of day, with more severe crashes occurring in the period 00:00 to 05.59 than at other times of the day.

Table 1: Previous studies that investigated the effect of darkness on motorcycle RTCs using police report databases.

Study	**Sample**	**Focus of study**	**Definition of Dark and Light**	**Results: effect of darkness on RTC**	
				severity	**risk**
Studies concluding differences between daylight and dark					
Rowland et al., (1996)	US, Washington State Patrol Records for 1989.	All motorcycle RTCs	Crashes were classified in dark, including hours after dusk and up to predawn.	More likely to involve head injury.	Not studied
Savolainen & Mannering (2007)	US, Indiana police reported motorcycle crashes for 2003 to 2005.	All motorcycle RTCs	Crashes were classified as daylight or darkness from the database. No specific definition was given.	More RTCs involving severe injury.	Not studied
Pai & Saleh (2007)	UK, STATS 19 data for 1999 to 2004.	Motorcycle RTCs at T-junctions.	Crashes were classified as daylight or darkness from the database. No specific definition was given.	More likely to be severely injured at stop and give way intersections.	Not studied
Pai (2009)	UK, STATS 19 database for 1999 to 2004.	Motorcycles in multi-vehicle RTCs.	Crashes were grouped by the time (midnight/early morning/evening/rush hours).	‘Right if way’ is more likely to be violated at stop/give way-controlled junctions.	Not studied
Shaheed & Dissanayake (2011)	US, Kansas Accident Records for 2004 to 2008.	All motorcycle RTCs	Crashes were split into daylight, dawn/dusk and darkness.	More likely to be involved in a fatal and serious RTC.	Not studied
Shaheed et al., (2011)	US, Iowa Department for Transport crash database, 2001 to 2008.	Motorcycles in two-vehicle RTCs.	Crashes were classified as daylight, dusk, dawn and darkness from the database.	More fatal and serious RTCs.	Not studied
Manan et al., (2017)	Malaysia, Malaysian Institute of Road Safety Research records, for 2010 to 2012.	All motorcycle RTCs	Crashes were classified as daylight, early morning/evening and darkness from the database.	Multiple vehicle RTCs are more likely to occur during daylight compared to single vehicle RTCs.	Not studied
Studies concluding no differences between daylight and dark					
Cercarelli et al., (1992)	Australia, Road Accident Prevention Research Unit’s Road Injury Database for 1988.	Motorcycles in two-vehicle RTCs (also, car-car RTCs)	Crashes were classified as daylight and darkness from the database. Crashes occurring at dusk and dawn were not included.	Car-motorcycle and car-car RTCs did not differ in their day/night distribution.	Motorcycles and cars did not differ in their RTC risk
Shaheed & Gkritza (2014)	US, Iowa Department for Transport crash database for 2001 to 2008.	Single vehicle motorcycle RTCs.	Crashes were classified in dark (yes or no).	RTCs less likely to be fatal.	Not studied

Note: Pai & Saleh (2007) use the term ‘three legged junctions’ instead of T-junctions.

The causes of RTCs are many and complex (Guo et al., 2010). For those RTCs after dark, there are many contributory factors in addition to ambient light which may play a role, including increased alcohol consumption (Di Bartolomeo et al., 2009) and vehicles travelling at higher speeds due to decreased traffic density (Bassani et al., 2016). It is difficult to isolate RTCs where light conditions are the primary cause. For example, consider a driver not seeing an oncoming motorcycle at a junction and pulling out into their path: this may be due to the number of other vehicles on the road (traffic density) rather than the ambient lighting conditions.

To isolate the role of ambient light on RTCs, previous studies have taken advantage of the twice-yearly clock change, examining RTCs that occur immediately before and after a clock change associated with Daylight Savings Transition. Clocks are bought forward by one hour on a date in Spring, and put back on a date in Autumn. The clock change approach compares RTCs during particular time windows, in pairs of weeks, where in one week the time window is dark, and in the other week the time window is daylight. This is done with the assumption that other factors such as journey purpose, traffic density and alcohol consumption, remain similar in the before and after weeks.

In some of these studies (Johannson et al., 2009; Uttley & Fotios, 2017) the boundary between dark and daylight was a solar altitude of 0°; by not omitting the twilight period the effect of ambient light may have been under-estimated (Fotios et al., 2020). This is supported by previous research which studied the effect of darkness on all RTCs in the Netherlands between 1987 and 2006. If was found that the effect during twilight is around 2/3 of the effect in darkness (Wanvik, 2009).

The current study therefore investigated the role of ambient light conditions on the risk of motorcycle RTCs, defining daylight and dark RTC cases in the manner recently proposed by Raynham et al. (2019). This should provide a more accurate estimate of the effect of darkness compared to studies which did not clearly define daylight and darkness and which may have included twilight periods. Risk factors considered in the current study were derived from the previous literature, with a particular focus on severity, situational factors (such as the road type and speed limit), junction type and junction control. The analysis omitted single-vehicle RTCs as these are less likely to be a result of impaired visibility or conspicuity.

In addition, four-wheel motor vehicle (FWMV) multiple-vehicle RTCs were also investigated to provide a datum to investigate whether there are specific contextual factors that significantly increase the risk of a motorcycle RTC after-dark compared to other motorised vehicles. This comparison is made as motorcycles are a minority group and tend to get overlooked in favour of FWMVs, resulting in recommendations based on the needs of drivers but not motorcyclists. Previous research has found that while comparisons of single and multiple vehicle motorcycle RTCs may be problematic as these have clearly different causes, comparing multiple vehicle car RTCs with multiple vehicle motorcycle RTCs is a more informative comparison as both visibility or conspicuity could be a common cause (Cercarelli et al., 1992).

2 Method

Data for this analysis were drawn from the STATS19 database of UK RTCs reported by the police. STATS19 records information about vehicles and situational factors of an RTC. These data are openly accessible via the UK Government website (DfT, 2019c). Data were used for RTCs that had taken place between the years of 2005 and 2015. These data were then filtered for RTCs that occurred the week before and after the Spring and Autumn clock change, resulting in 247,892 vehicle records. The dates of the weeks that were used over the 10-year period can be seen in Table 2. The dates are presented in four groups, which show before and after the Spring clock change and before and after the Autumn clock change. The actual clock change takes place at 1:00am on the Sunday morning, which is the first date that appears in the ‘After’ clock change dates in Table 2.

***Table 2*:** The weeks before and after the Spring and Autumn clock change between the years 2005-2015.

Spring Before		Spring After		Autumn Before		Autumn After	
Start	End	Start	End	Start	End	Start	End
20/03/2005	26/03/2005	27/03/2005	02/04/2005	23/10/2005	29/10/2005	30/10/2005	05/11/2005
19/03/2006	25/03/2006	26/03/2006	01/04/2006	22/10/2006	28/10/2006	29/10/2006	04/11/2006
18/03/2007	24/03/2007	25/03/2007	31/03/2007	21/10/2007	27/10/2007	28/10/2007	03/11/2007
23/03/2008	29/03/2008	30/03/2008	05/04/2008	19/10/2008	25/10/2008	26/10/2008	01/11/2008
22/03/2009	28/03/2009	29/03/2009	04/04/2009	18/10/2009	24/10/2009	25/10/2009	31/10/2009
21/03/2010	27/03/2010	28/03/2010	03/04/2010	24/10/2010	30/10/2010	31/10/2010	06/11/2010
20/03/2011	26/03/2011	27/03/2011	02/04/2011	23/10/2011	29/10/2011	30/10/2011	05/11/2011
18/03/2012	24/03/2012	25/03/2012	31/03/2012	21/10/2012	27/10/2012	28/10/2012	03/11/2012
24/03/2013	30/03/2013	31/03/2013	06/04/2013	20/10/2013	26/10/2013	27/10/2013	02/11/2013

23/03/2014	29/03/2014	30/03/2014	05/04/2014	19/10/2014	25/10/2014	26/10/2014	01/11/2014
22/03/2015	28/03/2015	29/03/2015	04/04/2015	18/10/2015	24/10/2015	25/10/2015	31/10/2015

For each RTC, solar altitude was calculated using the National Oceanic and Atmospheric Administration (NOAA) method (NOAA, 2005). This method requires the date, time and the location of an RTC (longitude and latitude), which were provided in the STATS19 data set. This method therefore produced a precise solar altitude for the location of each specific RTC. The solar altitude was also calculated at the exact same time for the paired week (i.e. if the RTC took place in the week before the clock change, then solar altitude was calculated also for 7 days after, at the exact same time).

These values allowed for the dataset to be filtered to find RTCs that occurred when the solar altitude was less than -6° and that if that RTC had taken place the exact same time in the other paired week, the solar altitude would have been greater the 0°. Similarly, RTCs that happened when the sun's altitude was greater than 0° and that if that RTC would have taken place the exact same time in the other paired week, the solar altitude would have been less than -6°. This procedure was completed separately for the morning and evening periods. The periods studied are summarised in the first five columns of Table 3.

The data were then filtered to provide a count of the number of motorcycles or FWMVs involved in an RTC. FWMVs included buses, mini-buses, cars, goods vehicles, taxis and vans. Single vehicle RTCs, for both motorcycles and FWMVs, were not included in this analysis. There are two reasons for this. First, single vehicle non-injury related crashes are less likely to be reported to police (and hence captured in STATS19) than multiple-vehicle crashes (Savolainen & Mannering, 2007). Second, single-vehicle crashes are more likely to be run-off-the road type which are a problem associated with fatigue rather than impaired vision (Sullivan & Flannagan, 2002).

For each of the time periods presented in Table 3, the number of RTCs that met the inclusion criteria were determined separately for motorcycles and FWMVs. These are known as the *case* RTCs, and the counts can also be seen in Table 3, along with the total RTCs that occurred in darkness and daylight.

It is possible that the change in the number of case RTCs that happened during the weeks of the clock change occurred due to other factors not associated with daylight, for example any seasonal influences such as the weather (Qiu & Nixon, 2008). Therefore, such changes in RTCs between darkness and daylight need to be compared to changes in control periods. This was accounted for by counting RTCs occurring in control periods either side of dusk and dawn, where the whole period was either daylight or dark.

In order to match the length of the control periods with the length of time window of the case RTCs, the time windows for the case RTCs were calculated separately for each study period (as seen in Table 3), and for each year. These time windows are summarised in S1. As can be seen in this table, the length of the case RTC time windows varied from 1 minute to 1 hour and 6 minutes, and therefore the same length time windows were used for the control periods. The time of the control periods were calculated by either adding or subtracting two hours to the original case time window to produce a daylight and dark control window. Two hours either side of the case window was chosen to ensure one control window was dark both before and after the clock change and one control period was daylight before and after the clock change. For example, if the morning case window was between 06:06-06:10am, then the dark control window was two hours before (04:06-04:10am), and the daylight control window was two hours after (08:06-08:10am). The opposite is true for evening case windows, with a case window of 18:45-19:45pm having a dark control window two hours after (20:45-21:40), and a daylight control window two hours before (16:45-17:40). Therefore, any RTCs that occurred in the dark control windows would have happened when the sun altitude was -6° or below, and RTCs that occurred in the daylight control windows would have happened when the sun altitude was 0° or above.

For each of the control periods, a count of the number of motorcycles and FWMVs to be involved in an RTC were examined. The RTCs that occurred during the dark control windows and the daylight control windows were summated. The total counts for these control periods are shown in Table 3.

A number of variables that are recorded in the STATS 19 dataset were selected to assess the risk of a motorcycle RTC after dark. The factors were chosen based on previous research of motorcycle safety, with a particular focus on severity of the RTC, situational factors (such as road type and speed limit) and junction factors (such as junction type and junction control).

The levels of each variable were based on the categories provided in STATS 19. Some categories were collapsed to provide a smaller number of levels, and some categories were removed. Categories were removed if the data were missing, out of range or unknown, and when there were too few instances of a particular category to perform a meaningful analysis. Table 4 shows each STATS 19 factor, the factor levels, and the levels which were used in subsequent analyses. It also shows the number of case RTCs that occurred at dark and daylight for each factor level, calculated separately for motorcycles and FWMVs.

<u>Table 3:</u> A summary of the study periods that were searched for RTCs that met the inclusion criteria, along with the number of case and control RTCs that occurred in each study period between the years 2005-2015, calculated separately for motorcycles and four-wheel motor vehicles.

Season	**Time of Day**	**Period**	**Light Condition of week**	**Light Condition of paired week**	**Number of Motorcycle RTCs**		**Number of FWMV RTCs**	
					Case	**Control**	**Case**	**Control**
Spring	Morning	Before	Light	Dark	4	84	27	1001
Spring	Morning	After	Dark	Light	3	73	42	837
Spring	Evening	Before	Dark	Light	126	385	1192	4411
Spring	Evening	After	Light	Dark	77	446	916	4992
Autumn	Morning	Before	Dark	Light	26	107	188	1619
Autumn	Morning	After	Light	Dark	13	100	149	1644
Autumn	Evening	Before	Light	Dark	184	505	1955	6071
Autumn	Evening	After	Dark	Light	283	508	2817	5947
				Total Dark	438	1073	4239	12814
				Total Light	278	1135	3047	13708
				Overall Total	716	2208	7286	26522

Table 4: A summary of the STATS 19 factors used in the current study, the factor levels and the number of case RTCs to occur in darkness and daylight for each factor level (with percentages). These were calculated for motorcycles and FWMVs separately. The 'Other' categories are not used in subsequent analyses.

Factor	**Levels**	**Motorcycles**		**FWMVs**	
		Dark	**Daylight**	**Dark**	**Daylight**
Accident Severity [1]	Slight	329 [75.1%]	232 [83.5%]	3839 [90.6%]	2706 [88.8%]
	Serious	105 [24.0%]	40 [14.4%]	375 [8.8%]	319 [10.5%]
	Fatal	4 [0.9%]	6 [2.2%]	25 [0.6%]	22 [0.7%]
Number of Vehicles [1]	2 vehicles	400 [91.3%]	254 [91.4%]	2945 [69.5%]	2307 [75.5%]
	3+ vehicles	38 [8.7%]	24 [8.6%]	1294 [30.5%]	740 [24.3%]
Weather [2]	Fine	357 [81.5%]	220 [79.1%]	3209 [75.7%]	2331 [76.5%]
	Rain/Snow/Fog	60 [13.7%]	49 [17.6%]	850 [20.1%]	610 [20.0%]
	Other	21 [4.8%]	9 [3.2%]	180 [4.2%]	106 [3.5%]
Urban or Rural [1]	Urban	338 [77.2%]	207 [74.5%]	2628 [62.0%]	1879 [61.7%]
	Rural	100 [22.8%]	71 [25.5%]	1611 [38.0%]	1168 [38.3%]
Road Type [3]	Dual Carriageway	53 [12.1%]	35 [12.6%]	1081 [25.5%]	558 [18.3%]
	One-way Street	7 [1.6%]	3 [1.1%]	51 [1.2%]	34 [1.1%]
	Roundabout	34 [7.8%]	15 [5.4%]	361 [8.5%]	221 [7.3%]
	Single Carriageway	341 [77.9%]	219 [78.8%]	2661 [62.8%]	2162 [71.0%]
	Other	3 [0.7%]	6 [2.2%]	85 [2.0%]	72 [2.4%]
Speed limit [1]	30 mph or below	330 [75.3%]	202 [72.7%]	2368 [55.9%]	1877 [61.6%]
	40-60 mph	93 [21.2%]	63 [22.7%]	1238 [29.2%]	880 [28.9%]
	70mph	15 [3.4%]	13 [4.7%]	633 [14.9%]	290 [9.5%]
Junction Type [3]	Crossroads	44 [10.0%]	36 [12.9%]	428 [10.1%]	301 [9.9%]
	Private Road	31 [7.1%]	24 [8.6%]	147 [3.5%]	114 [3.7%]
	Roundabout	39 [8.9%]	24 [8.6%]	478 [11.3%]	279 [9.2%]
	T-Junction	214 [48.9%]	110 [39.6%]	1175 [27.7%]	995 [32.7%]
	Not a junction	87 [19.9%]	66 [23.7%]	1702 [40.2%]	1132 [37.2%]
	Other	23 [5.3%]	18 [6.5%]	309 [7.3%]	226 [7.4%]
Junction Control [4]	Auto Traffic Signal	35 [8.0%]	19 [6.8%]	440 [10.4%]	303 [9.9%]
	Give way	312 [71.2%]	190 [68.3%]	2067 [48.8%]	1588 [52.1%]
	Not a junction	12 [2.7%]	9 [3.2%]	175 [4.1%]	209 [6.9%]
	Other	79 [18.0%]	60 [21.6%]	1557 [36.7%]	947 [31.1%]

[1] All motorcycle and FWMV RTCs were categorised into one of the factor levels.

[2] Fog or mist, raining with and without high winds, and snowing with and without high winds was collapsed to form the 'Rain/Snow/Fog' category. The 'Other' category comprised of data out of range, other and unknown conditions.

[3] 'Other' comprised of unknown data, data missing or out of range, and slip roads due to small case instances.

[4] 'Other' included data out of range, authorised person and stop sign due to small case instances. Auto traffic signal is the STAT19 label, which refers to signalised junctions.

3 Data Analysis

An Odds Ratio (OR) and associated 95% confidence intervals (CI) were used to compare the case RTC counts during darkness and daylight, with the control RTC counts. This OR gives a measure of the change in risk of an RTC associated with darkness compared with daylight conditions. Using Equation 1 and 2, an OR significantly greater than 1.0 indicates greater risk of an RTC at dark compared with daylight, after accounting for time-of-day and seasonal factors.

Equation 1

Odds Ratio= $\left. CaseDark/CaseDay \middle/ ControlDark/ControlDay \right.$

Equation 2

Confidence interval=

$$\exp\left(ln(OddsRatio) \pm 1.96 \times \sqrt{\frac{1}{CaseDark} + \frac{1}{CaseDay} + \frac{1}{ControlDark} + \frac{1}{ControlDay}} \right)$$

Where:

CaseDark is the count of RTCs that occurred when the solar altitude was -6° or below, and the paired week was 0° or greater

CaseDay is the count of RTCs that occurred when the solar altitude was 0° or greater, and the paired week was -6° or below

ControlDark is the count of RTCs in the Control periods on days when the Case RTCs would be in darkness

ControlDay is the count of RTCs in the Control periods on days when the Case RTCs would be in daylight

First, the ORs and 95% CI were calculated to show the change in risk at dark compared to daylight for motorcycle and FWMV RTCs. For each OR an associated p-value, to test significance of its departure from 1.0 was calculated using a Chi-square test. A significant p-value ($p<.05$) and a OR that is larger than 1.0 suggests that there is a significantly greater risk of an RTC associated with dark conditions compared with daylight conditions. A non-significant p-value, which is usually associated with 95% CIs crossing 1.0, suggests that there is not a significant change in risk of an RTC between daylight and dark conditions.

In addition to calculating the overall OR to estimate the change in risk associated with darkness compared to daylight, ORs were also calculated for the previously identified factor variables to provide additional detail about the circumstances of the RTC. ORs, CIs and associated p-values were calculated for each level within each factor, both for motorcycles and FWMVs separately.

The Tarone test of homogeneity (Paul & Donner, 1989) was used to assess whether there were significant differences between the ORs of pairs of levels within each factor, again analysed separately for motorcycles and FWMVs. Bonferroni correction was used to correct for multiple comparisons. These tests were designed to assess whether there were any significant changes in risk of an RTC at dark compared to daylight associated with different levels within a factor.

Finally, the ORs that were calculated each factor level were also compared for motorcycles and FWMVs to assess any significant differences in risk of an RTC associated with dark conditions and daylight conditions, also using the Tarone test of homogeneity.

4 Results

4.1 Overall changes in risk

Table 5 shows the ORs, 95% CIs and associated p-values for motorcycle and FWMV RTCs. As can be seen in Table 5, there is a greater risk of a motorcycle or FWMV RTC after dark compared with daylight. However, a Tarone test of homogeneity does not suggest that the ORs calculated for overall motorcycle and FWMV RTC risk are significantly different.

Table 5: ORs and 95% CIs associated with the change in risk at dark compared to daylight for a motorcycle and four-wheel motor vehicle to be involved in an RTC. The associated p-values indicate whether the OR is significantly different to 1.0. The comparison indicates whether the ORs are significantly different from one another.

	OR	**95% CI**	***p* value**	**Comparison**
Motorcycle RTCs	1.66	1.40-1.98	$p<.001$	$p=.22$
FWMV RTCs	1.48	1.41-1.57	$p<.001$	

4.2 Changes in risk for factor levels

Tables 6 and 7 show the ORs, 95% CIs and associated p-values for the different levels within each factor, calculated separately for motorcycles and FWMVs. It can be seen from these tables that, for the majority of factor levels, the OR is significantly greater than 1.0 for both motorcycles and FWMVs. This indicates the risk of that specific RTC is higher after dark compared with daylight for both types of road user.

Consider first the motorcycles. As shown in Table 6, there is a significant increase in risk for slight and serious RTCs after dark compared with daylight. This was not the case for fatalities, which could be due to a small number of observations (only four RTCs met the inclusion criteria at dark) preventing an accurate estimation of the population.

In addition, there was a significant increase in risk in darkness compared to daylight for multiple vehicle RTCs that involved two vehicles and three or more vehicles. The results do not suggest a difference between motorcycle RTCs in darkness compared to daylight during adverse weather (rain/snow/fog) and in rural areas, however, there is a significant increase in RTC risk when they occur in clear weather conditions and in urban areas. In terms of road type, there was a significant increase in risk, in darkness compared to daylight, for motorcycle RTCs that occur on dual carriageways, single carriageways and roundabouts, but not for RTCs that occur on one-way streets. This could be due to the small number of motorcycle RTCs on one-way streets. When focusing on the speed limit, there was a significant increase in risk, in darkness compared to daylight, for RTCs on roads with a speed limit of 30 mph or below and 40-60 mph, but not for roads with a speed limit of 70 mph.
In regards to junctions (Table 7), roundabouts and T-junctions lead to a significant increase in risk for a motorcycle RTC after dark compared to daylight. However, the data do not suggest a significant effect at crossroads, private entrances and RTCs that did not occur within 20 meters of a junction. Regarding junction control, there was a significant increase in motorcycle RTCs at junctions with a give way sign or controlled by auto traffic signals, but not for RTCs that did not occur within 20 meters of a junction.

Table 6: The darkness vs. daylight ORs for severity and situational levels, and the associated 95% CIs were calculated separately for motorcycles and four-wheel motor vehicles, and then compared. Within factor level OR comparisons are also shown, with the associated p-value which is Bonferroni adjusted.

		Motorcycles				**Four-Wheel Motor Vehicles (FWMVs)**				**Motorcycles vs. FWMVs**
Factor	**Levels**	**OR**	**95% CI**	**Comparison**	**Sig.**	**OR**	**95% CI**	**Comparison**	**Sig.**	
Accident Severity	Slight	**1.49*****	1.22-1.80	Serious	**p<.01****	**1.53*****	1.44-1.61	Serious	p-.02	p=.79
				Fatal	p=.50			Fatal	p=.06	
	Serious	**2.80*****	1.86-4.19	Slight	**p<.01****	**1.23***	1.04-1.45	Slight	p=.02	**p=.001*****
				Fatal	**p<.001*****			Fatal	p=.24	
	Fatal	0.91	0.22-3.68	Slight	p=.50	0.84	0.45-1.55	Slight	p=.06	p=.91
				Serious	**p<.001*****			Serious	p=.24	
Number of Vehicles	2 vehicles	**1.65*****	1.37-1.97	3+ vehicles	p=.69	**1.36*****	1.27-1.44	3+ vehicles	**p<.001*****	**p=.04***
	3+ vehicles	**1.86***	1.04-3.34	2 vehicles	p=.69	**1.91*****	1.72-2.12	2 vehicles	**p<.001*****	p=.93
Weather	Fine	**1.72*****	1.42-2.08	Rain/Snow/Fog	p=.13	**1.48*****	1.39-1.56	Rain/Snow/Fog	p=.83	p=.14
	Rain/Snow/Fog	1.19	0.77-1.85	Fine	p=.13	**1.50*****	1.33-1.68	Fine	p=.83	p=.33
Urban or Rural	Urban	**1.73*****	1.42-2.11	Rural	p=.42	**1.47*****	1.38-1.57	Rural	p=.62	p=.13
	Rural	1.47	1.03-2.08	Urban	p=.42	**1.52*****	1.39-1.65	Urban	p=.62	p=.87
Road Type	Dual Carriageway	**1.87****	1.13-3.07	One-way street	p=.63	**2.19*****	1.94-2.45	One-way street	p=.27	p=.54
				Roundabout	p=.22			Roundabout	p=.16	
				Single carriageway	p=.52			Single carriageway	**p<.001*****	
	One-way street	2.75	0.61-12.29	Dual Carriageway	p=.63	**1.66***	1.03-2.67	Dual Carriageway	p=.27	p=.53
				Roundabout	p=.87			Roundabout	p=.65	
				Single carriageway	p=.47			Single carriageway	p=.31	
	Roundabout	**3.16*****	1.61-6.18	Dual Carriageway	p=.22	**1.86*****	1.54-2.25	Dual Carriageway	p=.16	p=.14
				One-way street	p=.87			One-way street	p=.65	
				Single carriageway	p=.05			Single carriageway	**p<.001*****	
	Single Carriageway	**1.57*****	1.29-1.90	Dual Carriageway	p=.52	**1.29*****	1.21-1.37	Dual Carriageway	**p<.001*****	p=.06
				One-way street	p=.47			One-way street	p=.31	
				Roundabout	p=.05			Roundabout	**p<.001*****	
Speed limit	30 mph or below	**1.73*****	1.41-2.11	40-60mph	p=.60	**1.33*****	1.24-1.42	40-60mph	p=.02	**p=.02***
				70 mph	p=.50			70 mph	**p<.001*****	
	40-60 mph	**1.55***	1.07-2.23	30mph or below	p=.60	**1.54*****	1.40-1.70	30mph or below	p=.02	p=.99
				70 mph	p=.68			70 mph	**p<.001*****	
	70 mph	1.26	0.52-3.05	30pmh or below	p=.50	**2.35*****	2.00-2.75	30pmh or below	**p<.001*****	p=.17
				40-60 mph	p=.68			40-60 mph	**p<.001*****	

*=p<.05, **=p<.01, ***=p<.001.

Table 7: The darkness vs. daylight OR for junction factor levels, and the associated 95% CIs were calculated separately for motorcycles and four-wheel motor vehicles, and then compared. Within factor level OR comparisons are also shown, with the associated p-value which is Bonferroni adjusted.

		Motorcycles				Four-Wheel Motor Vehicles (FWMVs)				Motorcycles vs. FWMVs
Factor	Levels	OR	95% CI	Comparison	Sig.	OR	95% CI	Comparison	Sig.	
Junction Type	Crossroads	1.27	0.76-2.10	Private road	p=.75	1.48***	1.25-1.74	Private road	p=.16	p=.56
				Roundabout	p=.11			Roundabout	p=.02	
				T- Junction	p=.09			T- Junction	p=.19	
				Not a junction	p=.86			Not a junction	p=.48	
	Private Road	1.44	0.77-2.69	Crossroads	p=.75	1.18	0.89-1.55	Crossroads	p=.16	p=.56
				Roundabout	p=.25			Roundabout	p<.01**	
				T-Junction	p=.29			T-Junction	p=.50	
				Not a junction	p=.83			Not a junction	p=.05	
	Roundabout	2.37**	1.32-4.22	Crossroads	p-.11	1.96***	1.65-2.31	Crossroads	p=.02	p=.53
				Private road	p=.25			Private road	p<.01**	
				T- Junction	p=.67			T- Junction	p<.001***	
				Not a junction	p=.09			Not a junction	p=.03	
	T-Junction	2.07***	1.58-2.69	Crossroads	p=.09	1.31***	1.18-1.43	Crossroads	p=.19	p=.001***
				Private road	p=.29			Private road	p=.50	
				Roundabout	p=.67			Roundabout	p<.001***	
				Not a junction	p=.05			Not a junction	p<.01**	
	Not a junction	1.34	0.93-1.91	Crossroads	p=.86	1.59***	1.45-1.72	Crossroads	p=.48	p=.37
				Private road	p=.83			Private road	p=.05	
				Roundabout	p=.09			Roundabout	p=.03	
				T-Junction	p=.05			T-Junction	p<.01**	
Junction Control	Auto traffic Signal	1.93*	1.03-3.58	Give way	p=.77	1.57***	1.33-1.84	Give way	p=.21	p=.53
				Not a junction	p=.34			Not a junction	**p<.001**	
	Give way	1.75***	1.41-2.15	Auto traffic Signal	p=.77	1.40***	1.30-1.51	Auto traffic Signal	p=.21	p=.05*
				Not a junction	p=.37			Not a junction	**p<.001**	
	Not a Junction	1.09	0.40-2.97	Auto traffic Signal	p=.34	0.83	0.65-1.05	Auto traffic Signal	**p<.001**	p=.61
				Give way	p=.37			Give way	**p<.001**	

*=p<.05, **=p<.01, ***=p<.001.

For FWMVs, Table 6 shows that there is a significant increase in risk for slight and serious RTCs. Only a small number (25) of fatal RTCs at dark met the inclusion criteria, and therefore this result should be interpreted with caution. There is a significant increase in risk, in darkness compared to daylight, for RTCs that involve two or more vehicles, as well as in both clear and adverse weather conditions, and in urban and rural areas. For road type, there is a significant increase in RTCs, in darkness compared to daylight, that occur on dual carriageways, one-way streets, single carriageways and roundabouts. For speed limit, there was a significant increase in risk in darkness compared to daylight for RTCs on roads with a speed limit of 30 mph or below, 40-60 mph and 70 mph.

In Table 7, RTCs that occurred at crossroads, roundabouts, T-junctions and not within 20 meters of a junction produced a significant increase in risk at dark compared to daylight; however, RTCs at private entrances were not significant. Junctions with a give way sign or controlled by auto traffic signals showed a significant increase in RTC risk at dark compared to daylight, whereas instances not based around a junction were not significant.

4.3 Changes in risk within factors

Tables 6 and 7 also show the results from the Tarone tests of homogeneity that were used to assess whether there were significant differences between the ORs of pairs of levels within each factor.

For only one factor did the analysis of levels suggest a significant difference in the effect of darkness for motorcycle RTCs, which is accident severity. The OR for serious accidents is significantly higher than that for slight accidents. While the difference between serious and fatal RTCs is suggested to be significant, this may be due to the small sample of fatal RTCs. For FWMVs, there was a significant increase in risk, at darkness compared to daylight, for an RTC involving three or more vehicles compared two vehicles, an RTC occurring on a dual carriageway compared to a single carriageway, a roundabout compared to a single carriageway, and a road which has a 70mph speed limit compared to a 40-60mph or 30mph or below speed limit.

For junction factors, there was a significant increase in risk, at dark compared to daylight, for a FWMV to be involved in an RTC at a roundabout compared to a private road or T-junction, an RTC not within 20 meters of a junction compared to T-junction, and at a junction that has either an auto traffic signal (i.e. a signalised junction) or a give way sign compared to an RTC that did not occur within 20 meters of a junction.

4.4 Comparing motorcycles and FWMVs

The final columns of Tables 6 and 7 compare the OR established for motorcycles and FWMVs. These suggest that darkness has a significantly greater impact on motorcycle RTCs that are serious, that involve two vehicles (but not three or more), that are on a road with a speed limit of 30 mph or below, and that are at a T-junction and a give way junction.

5 Discussion

This analysis shows that darkness leads to an increase in RTC risk for both motorcycles and FWMVs compared to daylight. This confirms the findings of previous research which have looked at motorcycle injury severity (e.g. Rowland et al., 1996; Lin et al., 2003) but also extends previous findings for overall RTC risk. While this overall increase in risk was not significantly different for motorcycle and FWMV RTCs, when looking at particular contextual factors this suggests there are specific situations that need to be targeted to improve motorcycle safety after-dark.

For the majority of the contextual factors, darkness increased the risk of an RTC for FWMVs however, the contextual factors which increased motorcycles risk at dark were more specific. The significant contextual factors for motorcycle risk at dark centered around lower speed roads, urban areas, in clear weather, at roundabouts and T-junctions, and junctions controlled by a give-way sign or auto traffic signals.

There were also some differences between the two road user groups. While there was a significant increase in RTC risk for FWMVs after dark on urban and rural roads, on roads with a speed limit of 30mph or below, 40-60mph and 70mph, and in fine and adverse weather, there were no increase in risk for motorcycles after dark on rural roads, on roads with a 70mph speed limit, and in adverse weather. This finding is supported by previous research (Savolainen & Mannering, 2007; Pai & Saleh, 2007), with both studies suggesting that this finding could be a result of bad weather acting as a deterrent for risky behaviour such as speeding, and therefore motorcyclists may be better at managing risks in adverse weather compared to clear weather. However, given that cautious behaviours could also be applied to FWMV occupants, darkness may have a reduced risk for motorcycle RTCs due to motorcyclists being less likely to ride in adverse weather conditions, particularly in rural areas with a 70mph speed limit, where riding is more recreational (Blackman & Haworth, 2013). However, these potential explanations need to be further examined.

The current analysis also found that there are specific instances where the increase in risk after dark for motorcycles is significantly higher than for FWMVs. Firstly, there was a significantly larger increase in risk for a motorcycle to be involved in a serious RTC compared to a FWMV and their occupants. This finding is supported by previous research, which has found that motorcycle injuries are more severe at dark compared to daylight (e.g. Savolainen & Mannering, 2007).

In addition, the situations where motorcycles are associated with greater risk of an RTC after dark compared to FWMVs are involvement in a collision on a road having a speed limit of 30 mph or below, at a T-junction, and junctions controlled by a give way sign. These findings support the conclusions of previous work, which have found that the majority of multi-vehicle motorcycle RTCs after dark occur on low speed urban roads (81%) compared to higher speed rural roads (19%), with more than half of these urban multi-vehicle RTCs occurring at junctions, particularly T-junctions (Shaheed et al., 2011).

Given that low speed roads (30mph or below) and urban areas are related, as well as high speed roads (60-70mph) and rural areas, adjusted odds ratios were calculated separately for motorcycles and FWMVs for each speed limit while considering the predictor, urban or rural road. Again, it was found that there was a significant increase in risk of a motorcycle RTC at dark compared to daylight on lower speed roads, and a significant increase in risk on higher speed roads for FWMVs. The results are shown in S2.

Of the 438 motorcycle RTCs to occur at dark in the current analysis (see Table 3), 330 were on roads with a speed limit of 30 mph or below. Of these, 277 (84%) were located at junctions (of all types, including T-junctions and roundabouts) and 247 (75%) were at junctions controlled by a give-way sign. Of the 214 RTCs at a T-junction, 203 (95%) were controlled by a give way sign and 178 (83%) were on roads with a speed limit of 30 mph or below. It is clear that these specific situations are frequently describing the same RTC: in other words, there is a significant problem after dark for two-vehicle motorcycle RTCs at T-junctions controlled by a give way sign on a low speed road.

These specific characteristics mirror the most commonly reported causes of motorcycle crashes in daylight, with motorcycle RTCs being reported to occur on low speed urban roads (Clarke et al., 2007), particularly at uncontrolled T-junctions (Hole et al., 1996). In UK police reports for 2018 (DfT, 2018) the two most frequently given contributory factors were 'failure to look properly' (40%) and 'failure to judge path or speed' (21%). At unsignalised junctions, the decision to proceed requires awareness of the location, speed and travel path of approaching vehicles. At signalled junctions, the decision to proceed is made using the traffic signals. Unsignalised junctions therefore require more decision-making effort than do signalised junctions (Liu & Ozguner, 2007). Drivers who are not also motorcycle riders may not be able to sufficiently judge the speed and path of an approaching motorcycle. For example, they may be unaware of the tendency for motorcyclists to approach junctions at higher speeds than other traffic in urban areas (Walton & Buchanan, 2012). Drivers may perceive a lower degree of risk when pulling out in front of a motorcycle than a car. This is supported by a study showing that drivers at unsignalised junctions will pull out in front of motorcycles with a smaller gap than they do for other motorised vehicles (Robbins et al., 2018).

The conspicuity of approaching motorcycles at junctions may be decreased at dark due to poor visibility. Road lighting may be installed at junctions to reduce visual impairment after dark, and hence improve the visibility and conspicuity of objects. The analysis conducted by Bullough at al. (2013) suggests that lighting at junctions leads to a reduction in RTCs. Table 8 shows the number of RTCs identified as occurring after dark according to the current analysis, but categorised according to the ambient light condition recorded in STATS19. It also shows an OR associated with the increase in RTC risk on an unlit road compared to a lit road. An OR greater than 1.0 suggests a benefit of road lighting. For all RTCs, regardless of location, there is no significant change in risk for motorcycles between unlit and lit roads (p=.22), whereas for FWMVs there is an apparently significant benefit (p<.001) of road lighting. This was also the case for junction only locations, with a significant benefit of road lighting for FWMV RTCs (p<.001), but not for motorcycle RTCs (p=.44). These data suggest that while lighting may be an effective countermeasure to reduce RTCs, this benefit depends on the type of road user. If motorcycle RTCs occurring at junctions are to be reduced, then their conspicuity needs to be raised by an approach other than road lighting.

To improve motorcyclists' cognitive conspicuity to drivers, one approach is to raise awareness of motorcycles through education (Langham & Moberly, 2003), although previous studies have suggested that education has no effect on RTC risk (Nasvadi & Vavrik, 2007). To improve motorcyclists' perceptual conspicuity to drivers there is some evidence that visual aids such as reflective or fluorescent clothing may be beneficial (Roge et al., 2017; Wood et al., 2012). To be effective, however, such devices need to be instantly recognisable as a motorcyclist and not just a visible but unidentifiable object.

The RTCs in Table 8 are those identified in the current analysis using solar altitude as occurring after dark. It is therefore surprising that 15.30% of all motorcycle RTCs (and 15.92% of FWMV RTCs) were categorised by police as occurring in daylight. This suggests an error in either the time or ambient light condition recorded for those RTCs, which may have misled RTC studies using these data. The current analysis used the time of day data from which the ambient light condition at the time of the RTC was established. The discrepancy may also reflect the difficulty of defining ambient light conditions by observation during the twilight period.

Table 9 shows the ORs of previous studies (of those reported in Table 1) that investigated the increase in risk of a motorcycle RTCs at dark for the factors of severity and junction control. These ORs are reported alongside the ORs calculated in the current study. Although the studies that used an OR method from Table 1 are generally studies that separated darkness and daylight from twilight periods, it can still be seen that the change in risk of a motorcycle RTC, associated with dark conditions compared with daylight conditions, is lower than those in the current analysis. This suggests that previous studies have underestimated the risk of motorcycle RTCs at dark by not clearly defining daylight and darkness. This follows previous findings which found that a more precise method for distinguishing between RTCs in daylight and after dark reveals a greater effect of darkness (Fotios et al., 2020).

However, it is acknowledged that some previous studies reported in Table 1 (e.g. Rowland et al., 1996; Shaheed & Dissanayake, 2011) present adjusted ORs, accounting for confounding variables. While the current method used to calculate ORs aims to minimise the influence of confounding factors (Johansson et al., 2009), multinomial logistic regressions were also conducted to model the effect of three predictor variables on estimated ORs for each factor level variable. The predictor variables that were available in the STATS 19 database were hour of RTC, year of RTC and day of the week. The results are shown in S3. It was found that for motorcycles, all adjusted ORs fell within the 95% CI of the calculated ORs in the original analysis. For FWMVs, the adjusted OR for four variables did not fall within the original 95% CI, with 2 vehicle, 3+ vehicles, fine weather and 30mph or below RTCs producing smaller ORs than the original analysis. However, given that the difference in risk between these adjusted ORs is larger than the original OR when comparing motorcycle and FWMVs, these significant comparisons still hold.

It is possible that changes in the frequency of RTC in the control periods could systematically vary with time of day, and therefore estimates of effect of the transition of light may also depend on the choice of the comparison control hours (Johansson et al., 2009). For this reason, two sensitivity analyses were conducted. First, for the control periods used in the current analysis, the difference between the darkness and daylight controls were compared. Second, ORs were calculated using control periods which were three hours either side of the case periods, as opposed to two hours as used in the current analysis. The results are shown in S4. In all cases the OR is significantly greater than 1.0 – the effect of ambient light on RTCs is retained. Although there was some variation in ORs when only dark controls or daylight controls are considered, these differences were not significant for motorcycles or FWMVs. There was less variation in ORs when considering both daylight and dark control periods together, with no significant differences between control periods that were two and three hours either side of the case period, for both motorcycles and FWMVs.

There are potential limitations to the STAT19 database. Firstly, the database may have a problem of under-reporting, in that not all crashes are reported to the police (Haworth, 2003). Previous research has found that under-reporting for motorcycle crashes has been seen to be greater for less severe crashes (Diamantopoulou et al., 1997), which in turn inflates the average severity of crashes. However, the current findings suggest a significant increase in risk after dark is found for slight and severe crashes, but not for fatal crashes. In addition, by omitting single-vehicle RTCs from the current analysis, this should reduce the levels of under-reporting in the current sample as there is less motivation when a single-vehicle crash occurs to report the RTC for insurance reasons (Lujic et al., 2008). Secondly, the instructions provided to police for completing the STATS 19 form do not provide clear advice as to how the time of an RTC should be established (DfT, 2011). It is likely that this time refers to when the police officer was notified of the RTC (Imprialou & Quddus, 2019). The average interval between an RTC occurring and the police being notified is around 5-5.9 minutes (Brodsky, 1993; Blatt et al., 2009). For the current data, an RTC recorded 6 minutes after its occurrence would result in a change in solar altitude of between 0.6 to 0.9°. For an RTC occurring in the morning, the higher altitude would mean an increase in ambient light: for an RTC occurring in the evening the lower altitude would mean a decrease in ambient light. Compared with the civil twilight interval of six degrees, this is likely to be a negligible effect.

Finally, it is also acknowledged that there may be fewer motorcycles on the road when it is dark compared to when it is daylight (Rowland et al., 1996), and thus reduced exposure to RTCs during night. Adjusting for exposure of motorcycles would require data about the effect of darkness on exposure for motorcycles for each situational factor, and these data do not appear to be available.

6 Conclusions

The current article investigated the role of ambient light (dark or daylight) on motorcycle RTCs, using data from the STATS19 database between the years 2005 to 2015, and compared these to the effect on FWMV RTCs in the same period.

This analysis was conducted using a more precise method for distinguishing between RTCs in daylight and after dark than used in previous studies. This led to higher ORs than previous studies, indicating a stronger detrimental effect of darkness.

Darkness increased the risk of an RTC for both motorcycles and FWMVs. However, this increase in risk was significantly larger for motorcycles than FWMVs for RTCs involving two-vehicles, when the speed limit is 30mph or below, at T-junctions, and at junctions controlled by a give way sign.

Uncontrolled T-junctions appear to pose a significant risk for motorcycles after dark. For junctions in general, road lighting reduces the OR of an RTC for FWMVs but is not suggested to be of benefit for motorcycles. Further work is needed to determine how motorcycle conspicuity can be raised at junctions.

Table 8: The number (and percentage) of RTCs identified as occurring after dark in the current analysis, categorised according to the light condition recorded by police in the STATS19 database for 2005 to 2015. These were calculated separately for junction only RTCs and all RTCs. ORs and CIs associated with the change in risk on unlit roads compared to lit roads for motorcycle and FWMVs were also calculated, along with p-values that indicate whether the OR is significantly different to 1.0.

Vehicle type	RTC location	Lighting Condition as Categorised in STATS19	Number of RTCs (and %)	Unlit vs. Lit OR	95% CI	*p* value
Motorcycles	**Junction Only**	Darkness (Lit Road)	261 (74.36%)			
		Darkness (Unlit Road)	22 (6.27%)	1.29	0.66-2.52	p=.44
		Darkness (Lighting Unknown)	9 (2.56%)			
		Daylight	59 (16.81%)			
	All RTCs	Darkness (Lit Road)	324 (73.97%)			
		Darkness (Unlit Road)	38 (8.68%)	1.38	0.82-2.33	p=.22
		Darkness (Lighting Unknown)	9 (2.05%)			
		Daylight	67 (15.30%)			
FWMVs	**Junction Only**	Darkness (Lit Road)	1792 (70.63%)			
		Darkness (Unlit Road)	250 (9.85%)	1.61	1.32-1.96	p<.001
		Darkness (Lighting Unknown)	81 (3.19%)			
		Daylight	414 (16.33%)			
	All RTCs	Darkness (Lit Road)	2717 (64.10%)			
		Darkness (Unlit Road)	701 (16.54%)	1.30	1.15-1.46	p<.001
		Darkness (Lighting Unknown)	146 (3.44%)			
		Daylight	675 (15.92%)			

Table 9: Previous studies from Table 1 that used an OR analysis to investigate the increase in risk of a motorcycle RTCs at dark for factors of severity and junctions, compared to the current OR analysis using a more precise definition of dark and daylight.

Study	**Definition of lighting**	**Comparison**	**OR**	**95% CI**
Accident Severity- Serious				
Shaheed & Dissanayake (2011)	Dawn-Dusk	Daylight	1.01	0.59-1.72
	Darkness	Daylight	2.04	1.53-2.72
Current Study	Solar altitude=< -6°	Solar altitude=> 0°	2.80	1.86-4.19
Junction Control - Give way				
Pai (2009)	Morning (00:00-06:59)	Daylight (09:00-15:59)	1.34	-
	Evening (18:00-23:59)	Daylight (09:00-15:59)	1.21	-
Current Study	Solar altitude= -6°	Solar altitude=> 0°	1.75	1.41-2.15

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Declaration of Interests:

None.

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