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A comparison of approaches for investigating the impact of ambient light on road traffic collisions

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A recent paper proposed a more precise approach for investigating the impact of ambient light (daylight versus after dark) on road traffic collisions. The present paper first repeated that analysis of road traffic collisions in the UK to test reproducibility; it then extended the analysis to determine whether the greater precision affected the outcome of road traffic collision analyses. Results of the previous analysis were reproduced in terms of the direction of the effect, but the repeated analysis found greater differences between daylight and darkness. The odds ratio determined using the new method led to higher odds ratios than the analyses used in some past studies, suggesting that past studies may have underestimated the detrimental effect of darkness on road traffic collision risk.

1. Introduction

The risk of a road traffic collision (RTC) is influenced by many factors, including the alertness, intoxication and visual status of the driver,[1,2] traffic speed,[3] traffic composition[4] and distraction from secondary tasks.[5,6]

After dark, there is a deterioration in visual performance, including reductions in contrast discrimination, depth perception and reaction time[7] which reduces the probability and speed of detecting potential hazards that might lead to an RTC. Road lighting partially offsets this,[8–12] and is assumed to improve drivers' ability to detect potential hazards not otherwise revealed by vehicle headlights.[13] A reduction in reaction time to detection allows an earlier braking or avoidance response which can prevent a collision or at least reduce the speed of impact. One reason for installing road lighting is, therefore, to reduce the frequency and severity of RTCs after dark.

One approach to measuring the impact of ambient light on RTC rate is to compare the frequencies of RTCs that occur in daytime and darkness. To isolate the effect of ambient light from other factors which influences RTC risk, the comparison is made of RTC frequencies for a specific period of the day, which is daylit at one moment and dark at another. The clock change approach takes advantage of the twice-yearly change to clocks, in which clocks are advanced or retarded by 1 hour in response to changes in daylight: a certain time of day is therefore daylit immediately before clock change and dark immediately following clock change (or vice versa). The numbers of RTCs occurring within specific time windows are compared for the days immediately before, and immediately after, the clock change date. The clock change approach has been used to study the effect of ambient light on RTCs[14,15] and travel behaviour.[16]

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An alternative to the clock change approach is to take advantage of the seasonal variation in daylight hours across the whole year and pick a period of the day which is daylit for one part of the year and dark for the remaining part. This approach permits a greater amount of data to be included in the analysis since it captures RTCs occurring year-round and not just those in the week(s) before and after clock changes. This may be important when disaggregating the analysis to smaller geographic areas, e.g. when trying to calculate individual odds ratios (OR) for specific locations. However, it exacerbates the influence on RTCs of seasonal effects such as weather. To isolate the effect of ambient light from other seasonal variations, an OR can be used.[17] The OR compares the day/dark ratio of RTCs in the case period with the corresponding ratio of RTCs for a control period: control periods are those which remain daylit or dark across the evaluation period. The whole-year method has also been used to study RTCs[2,18] and travel behaviour.[19]

One key point of these analyses is the definition of darkness, or, the degree to which RTCs occurring in twilight were omitted. Twilight is the partially daylit periods immediately before morning sunrise and immediately after evening sunset, when daylight persists due to the reflection and scattering of sunlight towards the horizon of a terrestrial observer.[20] The twilight periods are thus not fully daylit nor dark but a gradual transition between the two, and RTCs occurring in twilight introduce ambiguity as to the effect, if any, of ambient light. There are various standardised stages of twilight. Civil twilight is the stage where there is sufficient daylight illuminance to enable outdoor civil activity to continue unhindered without resorting to the use of electric road lighting: it is the period where solar altitude is between 0° and -6°.[20]

The RTC study by Johansson *et al.*[18] defined darkness as after sunset and before sunrise (a solar altitude of 0°), which they defined as ‘approximately correct’. They used a 1-hour time window which, according to this definition, was daylit for part of the year and dark for part of the year. Clearly, there would be periods when this time window was in twilight. Sullivan and Flannagan[14,21] set their dark hour as that occurring before the start of civil twilight in the morning and after the end of civil twilight in the evening.

While Johansson *et al.*[18] also considered RTCs in control periods to account for seasonal variation in their whole-year analysis, Sullivan and Flannagan[14,21] did not. Sullivan and Flannagan[14] compared RTC rates in the two weeks before clock change with the two weeks after clock change (see their Figures 9, 10, 12, 13 and 14) with an assumption that ‘traffic volume, pedestrian exposure, and weather do not substantially change shortly before and shortly after the time change’. In later work, Sullivan and Flannagan[21,22] used five-week windows before and after clock change. Ferguson *et al.*[23] considered 13 weeks before and 9 weeks after each clock change, and thus 44 weeks altogether, which approaches the whole-year period of Johansson *et al.* An assumption of insubstantial seasonal effects becomes less robust as the evaluation period increases.

A recent study by Raynham *et al.*[24] introduced a further development to the clock change method of investigating the effect of ambient light on RTCs. They considered RTCs in the seven day periods before and after clock change, and defined darkness according to civil twilight rather than sunset and sunrise. In addition, they added a further requirement: an RTC was considered to be within the case window if it occurred in darkness (a solar altitude of $<-6^\circ$) but also if it was daylight (a solar altitude of $\geq 0^\circ$) for the same time of day in the opposite week (e.g. the week before clock change for an RTC occurring after dark in the week after clock change).

This resulted in case periods which were reduced in duration (from 5 to 33 minutes – see Table 6 in Raynham *et al.*) compared with the 1-hour periods used by others.[14,18,21] However, Raynham *et al.* did not report the degree to which the outcome of their analysis differed from previous work.

This paper reports four analyses of RTCs carried out to compare the differences between methods of analysis. First, the analysis of Raynham *et al.*[24] was repeated to test reproducibility,[25] the degree to which consistent results are reached when the same data are independently re-analysed. The Raynham *et al.* method was then extended to establish an OR. Third, the analysis was conducted using 1-h case and control time windows. Finally, a whole-year analysis was conducted.

2. Method

2.1 Analysis 1: Reproduce the analysis of Raynham *et al.*

This research used data from the STATS 19 database[26] of police-reported road traffic collisions (RTCs) that occurred in England, Scotland and Wales in the period 2005 to 2015. This is the same data source and the same period as was used by Raynham *et al.*[24] STATS 19 includes a data file for all vehicles involved in an RTC, and another which provides details on all the casualties involved: this allows for three sorts of data – the number of collisions, the number of vehicles involved and the number of casualties. The number of casualties can be further categorised as vehicle occupants (which includes all casualties that are not pedestrians or cyclists), pedestrians and cyclists.

For the clock-change analysis, the database was filtered for RTCs that occurred the seven days before and seven days after the Spring and Autumn clock change date for the UK.[27] The dates of the weeks that were used over the 11-year period are shown in Table 1. Clock change takes place at 1:00 a.m. on a Sunday morning, which is the first date that appears in the 'After' clock change dates. This left 134,709 RTC records, 247,892 vehicle records and 183,090 casualty records. There were more casualty and vehicle records than RTC records because there were instances where there was more than one casualty or vehicle per RTC.

Solar altitude was calculated using the National Oceanic and Atmospheric Administration method[28] for each RTC. This method requires the date of the collision, the time zone, and the location (longitude and latitude) of the collision, all of which data are available in the STATS 19 data set. Solar altitude was also calculated at the exact same time for the paired week (i.e. if the collision took place in the week before the clock change, this was solar altitude in the week after clock change).

These values allowed for the data to be filtered to find RTCs that met two criteria: first, that the RTC occurred when the solar altitude was less than -6°, and second, that if that collision had taken place on the exact same day and time in the paired week, that the solar altitude would have been greater than 0°. Similarly, RTCs that happened when the sun's altitude was greater than 0° and that if that collision would have taken place the exact same time for the same day in the paired week, the solar altitude would have been less than -6°. These case collisions were identified separately for the morning and evening. The study periods are summarised in Table 2. The numbers of case collisions that met the inclusion criteria are shown in Table 3.

Two control periods were established, one in which it was dark for both weeks before and after clock change, and one in which it was daylight before and after the change: the same control periods were used in previous work.[24] Table 4 shows the control periods and the numbers of RTCs that happened during each period. While, technically, one control

Table 1 The weeks before and after the Spring and Autumn UK clock change between the years 2005 and 2015

Spring before		Spring after		Autumn before		Autumn after	
Start	End	Start	End	Start	End	Start	End
20 March 2005	26 March2005	27 March2005	02 April 2005	23 October 2005	29 October 2005	30 October 2005	05 November 2005
19 March 2006	25 March2006	26 March2006	01 April 2006	22 October 2006	28 October 2006	29 October 2006	04 November 2006
18 March 2007	24 March2007	25 March2007	31 March 2007	21 October 2007	27 October 2007	28 October 2007	03 November 2007
23 March2008	29 March2008	30 March2008	05 April 2008	19 October 2008	25 October 2008	26 October 2008	01 November 2008
22 March2009	28 March2009	29 March2009	04 April 2009	18 October 2009	24 October 2009	25 October 2009	31 October 2009
21 March2010	27 March2010	28 March2010	03 April 2010	24 October 2010	30 October 2010	31 October 2010	06 November 2010
20 March2011	26 March2011	27 March2011	02 April 2011	23 October 2011	29 October 2011	30 October 2011	05 November 2011
18 March2012	24 March2012	25 March2012	31 March 2012	21 October 2012	27 October 2012	28 October 2012	03 November 2012
24 March2013	30 March2013	31 March2013	06 April 2013	20 October 2013	26 October 2013	27 October 2013	02 November 2013
23 March2014	29 March2014	30 March2014	05 April 2014	19 October 2014	25 October 2014	26 October 2014	01 November 2014
22 March2015	28 March2015	29 March2015	04 April 2015	18 October 2015	24 October 2015	25 October 2015	31 October 2015

Table 2 Periods that were searched for Case RTCs

Season	Time of day	Week	Light condition of the *Case* week
Spring	Morning	Before	Light
		After	Dark
	Evening	Before	Dark
		After	Light
Autumn	Morning	Before	Dark
		After	Light
	Evening	Before	Light
		After	Dark

Note: The light condition of the paired week was the alternative to that of the *Case* week.

period is sufficient, different control periods may result in slightly different ORs[16] and thus two were used in the current analysis.

According to our understanding of their work, this method of analysis was identical to that used by Raynham *et al*.[24]

2.2 Analysis 2: Odds ratio for Raynham *et al.*

The first analysis calculated the number of 'Case' collisions using the Raynham *et al*. approach to distinguish RTCs in daylight and darkness. However, following Raynham *et al*., the length of the control periods (one hour) was much longer than the short durations of the case periods. Given that all previous research has matched the case and control period time windows, to determine ORs, the current analysis calculated the duration of the 'Case' collision time windows for each year, and used control periods which were the same overall length. These are summarised in Appendix 1.

The times of the control periods were determined by either adding or subtracting 2 hours to the case time window, producing a daylight control window (where the whole period had a solar altitude of 0° or above), and a dark control window (where the whole period had a solar altitude of −6° or below). For example, if the morning case window was between 06:06 and 06:10, then the dark control window was 2 hours before this

Table 3 The numbers of collisions, vehicles and casualties in the case period

Season	Time of day	Period	Light condition	Number of collisions	Number of vehicles	Casualties			
						Total casualties	Vehicle occupants	Pedestrians	Cyclists
Spring	Morning	Before	Light	24	41	32	31	0	1
Spring	Morning	After	Dark	26	52	34	31	0	3
Spring	Evening	Before	Dark	931	1696	1246	955	195	96
Spring	Evening	After	Light	754	1340	1012	765	142	105
Autumn	Morning	Before	Dark	147	277	173	129	20	24
Autumn	Morning	After	Light	113	210	135	113	5	17
Autumn	Evening	Before	Light	1451	2738	1862	1443	264	185
Autumn	Evening	After	Dark	1932	3826	2662	2063	363	236

Note: Casualty numbers are also broken down into vehicle occupants, pedestrians and cyclists for analysis 1.

Table 4 Definition of the control periods, and the numbers of collisions, vehicles and casualties before and after the clock change for analysis 1

Control Periods				Before			After		
				Number of collisions	Number of vehicles involved	Number of casualties	Number of collisions	Number of vehicles involved	Number of casualties
Spring	Morning	04:10–05:10	Dark	161	255	214	204	305	286
Spring	Morning	07.30–08:30	Light	2381	4601	3036	1923	3648	2396
Spring	Evening	16:50–17:50	Light	2646	4937	3485	2966	5623	3974
Spring	Evening	20:50–21:50	Dark	1050	1827	1504	1131	1982	1662
Autumn	Morning	04:50–05:50	Dark	309	514	378	321	518	406
Autumn	Morning	08:30–09:30	Light	2430	4581	3112	2732	5158	3510
Autumn	Evening	14:40–15:40	Light	2660	4912	3550	2516	4553	3433
Autumn	Evening	18:40–19:40	Dark	2269	4195	3074	2338	4272	3149

(i.e. 04:06 to 04:10), and the daylight control window was 2 hours after this (i.e. 08:06 to 08:10). Table A1 shows the timings for these two control windows.

ORs were determined using equation (1) and associated 95% confidence intervals (CI) were determined using equation (2). This OR gives a measure of the change in risk of an RTC associated with dark conditions compared with daylight conditions. An OR significantly greater than one indicates a greater risk of an RTC in darkness compared with daylight, after accounting for time-of-day and seasonal factors. The number of RTCs that occurred during the case periods is those used in analysis 1 as shown in Table 3. The number of RTCs that occurred during these control periods is summarised in Table 5.

$$\text{Odds ratio} = (CaseDark/CaseDay)/(ControlDark/ControlDay) \quad (1)$$

$$\text{CI} = \exp\left(Ln(OddsRatio) \pm 1.96 \times \sqrt{\left\{\frac{1}{CaseDark} + \frac{1}{CaseDay} + \frac{1}{ControlDark} + \frac{1}{ControlDay}\right\}}\right) \quad (2)$$

Table 5 The number of collisions, number of vehicles involved, and number of casualties, broken down into vehicle occupants, pedestrians and cyclists that occurred during the Dark and Day control windows detailed in Table A1

Season		Period	Case light condition	Number of		Number of casualties			
				RTCs	Vehicles	Total	Vehicle occupants	Pedestrians	Cyclists
Spring	Morning	Before	Light	614	1159	781	598	101	82
		After	Dark	512	945	626	478	77	71
Spring	Evening	Before	Dark	3354	6178	4568	3606	579	383
		After	Light	3720	6928	5114	4077	629	408
Autumn	Morning	Before	Dark	1237	2276	1554	1195	193	166
		After	Light	1229	2267	1568	1225	189	154
Autumn	Evening	Before	Light	4670	8532	6343	4939	965	439
		After	Dark	4630	8427	6290	4804	1020	466

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 day and dark Control periods on days when the Case RTCs would be in darkness.
- *ControlDay* is the count of RTCs in the day and dark Control periods on days when the Case RTCs would be in daylight.

2.3 Analysis 3: Defined case hour

The third analysis employed a previously used assumption regarding the definitions of daylight and darkness, using 1-hour case and control periods.[15] Following that previous study, this analysis considered only the evening daylight-to-dark transition. The case hour was defined as the hour immediately preceding the time of sunset on the day of the Spring clock change, and the hour immediately after the time of sunset on the day of the Autumn clock change. During Spring, the case hour changes from darkness before the clock change to daylight after the clock change, and in Autumn the case hour changes from daylight before the clock change to darkness after the clock change.

The time of sunset on the day of the clock change was calculated for each RTC using the National Oceanic and Atmospheric Administration method,[28] accounting for the date of clock change and location of the RTC. This resulted in a range of sunset times between 18:14 and 19:00 (GMT) during the Spring clock change and between 16:14 and 17:10 (GMT) during the autumn clock change.

In addition, two 1-hour control periods were identified, with these having the same light condition both before and after the clock change. Following previous research,[15] these were a daylight control hour between 14:00 and 14:59 and a dark control hour between 21:00 and 21:59. The total number of Case and control records was 22,324 collision records, 41,428 vehicle records and 31,291 casualty records.

2.4 Analysis 4: Whole year approach

For the whole year approach,[18] the case hour was set as 18:00–18:59: for one part of the year, this hour is in daylight, and for the other part it is in twilight or darkness. As with analysis 3, this considered only the afternoon daylight-to-dark transition. Choosing the same hour of the day to compare darkness and daylight, this limits the influence of non-light factors that may be associated with RTC risk. The two control hours, where the ambient light condition remained constant throughout the year, were 14:00–14:59 and 22:00–22:59. This method used a later dark control hour compared to the previous method as the whole year method includes summer time, and therefore the control hour needs to be later to ensure it is in darkness throughout the whole year. This data set comprised 320,826 collision records, 590,598 vehicle records and 438,471 casualty records.

3. Results

Table 6 shows the percentage changes in RTCs, according to type, for the case and control periods, as determined using analysis 1 and also the results reported by Raynham *et al*.[24]

The ORs and 95% confidence intervals were calculated for the number of collisions, number of vehicles involved and casualties, with casualties further broken down into vehicle occupants, pedestrians and cyclists. These data for analyses 2, 3 and 4 are shown in Table 7. For each OR, the departure from unity was calculated using a Chi-square test. An OR significantly ($p < 0.05$) greater than 1.0 suggests that there is a greater risk of an RTC associated with dark conditions compared with daylight conditions.

The ORs determined using the three methods of analysis were compared using the Tarone test of homogeneity[29] using Bonferroni to correct for multiple comparisons, with a new corrected *p*-value threshold of 0.017 (Table 8). For analysis 2, new ORs were calculated which only included evening RTCs, as only evening RTCs were used in analyses 3 and 4. As can be seen when comparing the ORs for analysis 2 in Tables 7 and 8, there is little difference between morning and evening RTCs (Table 7) and evening-only RTCs (Table 8).

4. Discussion

The first analysis reported the percentage increase in RTCs occurring after dark (Table 6). Analysis 1 led to greater differences than those reported by Raynham *et al*. for all instances, but the differences do not change the direction of effect. The percentage differences in RTC frequencies in light and dark periods (the Case periods) are greater than those found for the control periods: this suggests that the change in ambient light across Case periods was a significant factor. Percentage differences in control periods are in the opposite direction to those for

Table 6 The percentage increase in the number of 'Case' RTCs, number of vehicles and number of casualties in dark compared to daylight, and the percentage change during the hour control periods

RTC data	Current results		Results from Raynham *et al*.[24,a]	
	Percentage increase in the dark	Percentage change during corresponding control periods	Percentage increase in the dark	Percentage change during corresponding control periods
Number of collisions	29.6	−8.24	19.3	−6.8
Number of vehicles involved	35.2	−9.57	23.3	−8.0
Casualties: vehicle occupants	35.1	−10.0	21.2	a
Casualties: pedestrians	40.6	−3.4	31.7	a
Casualties: cyclists	16.6	−3.8	8.2	a
Casualties total	35.3	−8.7	21.3	−7.3

[a]Raynham *et al*. stated 'The breakdown of casualty types was not calculated for the control periods'.

Table 7 The darkness versus daylight odds ratio (OR), associated 95% confidence intervals (CI), and *p*-values for number of collisions, number of vehicles involved and casualties

RTC data	Analysis 2: Raynham et al.			Analysis 3: Defined case hour			Analysis 4: Whole-year approach		
	OR	95% CI	*p* value	OR	95% CI	*p* value	OR	95% CI	*p* value
Number of:									
Collisions	1.36	1.28–1.45	$p=0.001$	1.22	1.16–1.29	$p=0.001$	1.01	0.99–1.02	$p=0.34$
Vehicles	1.43	1.37–1.50	$p=0.001$	1.26	1.21–1.31	$p=0.001$	1.02	1.01–1.03	$p=0.01$
Casualties:									
Total	1.42	1.35–1.50	$p=0.001$	1.15	1.10–1.20	$p=0.001$	1.02	1.01–1.03	$p=0.01$
Vehicle occupants	1.45	1.37–1.54	$p=0.001$	1.13	1.07–1.19	$p=0.001$	1.04	1.02–1.05	$p=0.001$
Pedestrians	1.41	1.23–1.63	$p=0.001$	1.22	1.08–1.39	$p=0.002$	1.15	1.11–1.19	$p=0.001$
Cyclists	1.16	0.98–1.38	$p=0.090$	1.29	1.09–1.51	$p=0.002$	0.88	0.84–0.92	$p=0.001$

Case periods: we are yet to establish an explanation for this. An advantage of analysis using odds ratios is that the Case and control periods are considered together.

There may be two explanations for the differences between the findings of the current and Raynham *et al*. studies. First, it may be the result of researcher degrees of freedom,[30] the apparently arbitrary decisions made during the analysis. Second, there are differences in definition of the before/after clock change periods, as can be seen by comparing Table 1 in the current article with Table 5 in Raynham *et al*.[24] During the Autumn clock change for the years 2010, 2011 and 2012, the Raynham *et al*. analysis reports the two weeks before the clock change during that year, instead of one week before and one week after the clock change. Dates given for the Spring clock change in 2015 are also incorrect in Raynham *et al*., and the number of days for the weeks before and after the Autumn clock change of that year is not balanced (six days in the before period, eight in the after period).

Next consider the ORs as shown in Tables 7 and 8. ORs determined in accordance with the Raynham *et al*. approach with clock change data (analysis 2) led to ORs which depart further from unity than those estimated using the defined one-hour case and control windows with clock-change data (analysis 3). The whole-year method (analysis 4) led to the smallest ORs which, in many cases, were significantly smaller than those estimated using the other analyses. Generally, the stricter the approach for excluding RTCs occurring in twilight, the larger the odds ratio and thus the larger the estimated influence of darkness on RTCs. Analysis 3, for which the definition of darkness leads to a less extreme contrast between the two ambient light conditions than analysis 2, underestimates the effect of darkness on RTCs; ambient light levels may play a stronger role in RTC risk than concluded in earlier studies.

These trends between methods of analysis were found for the number of collisions, the number of vehicles involved, total casualties and vehicle occupant casualties, with significant differences between the ORs. Although the same trend existed for analyses of pedestrian casualties, the use of different criteria for defining dark and daylight did not cause significant differences between the ORs (Table 8). For cyclists, the ORs estimated with all methods were low, particularly the whole-year method.

In Tables 3 to 5, it can be seen that the number of RTCs in the morning is less than the number of RTCs in the evening, for both Spring and Autumn, for both the case and control periods. One possible change between these periods is traffic volume: Figure 1 of Raynham *et al*.[24] shows that traffic flows vary

Table 8 Comparison of odds ratios (ORs) determined using the three methods of analysis

RTC data	Analysis version	OR	95% confidence interval	Comparison with alternative analyses	Significance
Number of collisions	Raynham *et al*	1.36	1.28–1.45	Defined case hour	$p=0.008$*
				Whole year	$p=0.001$*
	Defined case hour	1.22	1.16–1.29	Raynham *et al*	$p=0.008$*
				Whole year	$p=0.001$*
	Whole year	1.01	0.99–1.02	Raynham *et al*	$p=0.001$*
				Defined case hour	$p=0.001$*
Number of vehicles involved	Raynham *et al*	1.43	1.37–1.50	Defined case hour	$p=0.001$*
				Whole year	$p=0.001$*
	Defined case hour	1.26	1.21–1.31	Raynham *et al*	$p=0.001$*
				Whole year	$p=0.001$*
	Whole year	1.02	1.01–1.03	Raynham *et al*	$p=0.001$*
				Defined case hour	$p=0.001$*
Casualties Total	Raynham *et al*	1.42	1.34–1.50	Defined case hour	$p=0.001$*
				Whole year	$p=0.001$*
	Defined case hour	1.15	1.10–1.20	Raynham *et al*	$p=0.001$*
				Whole year	$p=0.001$*
	Whole year	1.02	1.01–1.03	Raynham *et al*	$p=0.001$*
				Defined case hour	$p=0.001$*
Casualties: vehicle occupants	Raynham *et al*	1.47	1.38–1.56	Defined case hour	$p=0.001$*
				Whole year	$p=0.001$*
	Defined case hour	1.13	1.07–1.19	Raynham *et al*	$p=0.001$*
				Whole year	$p=0.002$*
	Whole year	1.04	1.02–1.05	Raynham *et al*	$p=0.001$*
				Defined case hour	$p=0.002$*
Casualties: pedestrians	Raynham *et al*	1.37	1.19–1.59	Defined case hour	$p=0.24$
				Whole year	$p=0.02$
	Defined case hour	1.22	1.08–1.39	Raynham *et al*	$p=0.24$
				Whole year	$p=0.34$
	Whole year	1.15	1.11–1.19	Raynham *et al*	$p=0.02$
				Defined case hour	$p=0.34$
Casualties: cyclists	Raynham *et al*	1.14	0.95–1.37	Defined case hour	$p=0.34$
				Whole year	$p=0.006$*
	Defined case hour	1.29	1.09–1.51	Raynham *et al*	$p=0.34$
				Whole year	$p=0.001$*
	Whole year	0.88	0.84–0.92	Raynham *et al*	$p=0.006$*
				Defined case hour	$p=0.001$*

Note: These data are for evening RTCs only.
*Significant differences (Bonferonni corrected threshold = 0.017).

with time of day. For the morning and evening periods of the current analyses (see Appendix 1), and for traffic flow in the UK (Figure 1 in Raynham *et al.*[24]), the morning period represents approximately 3.8% of daily traffic flows and the evening period approximately 5.8%. There is some evidence of an association between traffic volume and type and RTCs, for example an increase in the volume of light non-passenger cars increases the likelihood of more severe accidents (although this is not the case for passenger cars and heavy vehicles),[31] and the number of collisions involving pedestrians is expected to increase with an increase in the average annual daily traffic.[32] However, it is not known whether a change in traffic flow of 2% is sufficient to cause significant change in RTC numbers. An alternative explanation is that the Raynham *et al.* method leads to shorter case periods in the mornings than the evenings (see Appendix 1).

5. Conclusion

This paper has explored different approaches to analysing the impact of ambient light upon RTCs as recorded in the UK database STATS19 for the period 2005 to 2015. This study repeated the method of analysis used by Raynham *et al*. and found greater percentage differences in collisions and casualties between light and dark conditions. The Raynham *et al*. method follows previous work by defining the daylight and dark periods according to civil twilight (solar altitudes of $>0^\circ$ and $<-6^\circ$ respectively) but furthermore defined the case period as that which was dark before clock change and also daylight after clock change (and vice versa according to season and time of day): this results in smaller time windows than the 1-hour periods used in previous studies. This more precise approach for distinguishing between RTCs in daylight and darkness twilight led to greater ORs (analysis 2) than found if these criteria are relaxed (analyses 3 and 4), providing more compelling evidence of the detrimental effect of darkness on RTC rates.

None of the analyses reported here explicitly account for changes in exposure, for example, the reduced numbers of pedestrians and cyclists after dark.[16,19] Investigations of risk for these casualty groups may therefore underestimate the effect.

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Appendix 1 Time windows for the 'Case' collisions, and the time windows for the daylight and darkness control periods for Analysis 2: Raynham's approach with odds ratios

Year	Season	Time of day	Period	Light condition	Case control window	Dark control window	Day control window
2005	Spring	Morning	Before	Light			
			After	Dark	06:06–06:10	04:06–04:10	08:06–08:10
	Spring	Evening	Before	Dark			
			After	Light	18:47–19:45	20:47–21:45	16:47–17:45
	Autumn	Morning	Before	Dark			
			After	Light	06:55–07:21	04:55–05:21	08:55–09:21
	Autumn	Evening	Before	Light			
			After	Dark	17:00–17:50	19:00–19:50	15:00–15:50
2006	Spring	Morning	Before	Light			
			After	Dark	06:00–06:20	04:00–04:20	08:00–08:20
	Spring	Evening	Before	Dark			
			After	Light	18:45–19:40	20:45–21:40	16:45–17:40
	Autumn	Morning	Before	Dark			
			After	Light	06:59–07:20	04:59–05:20	08:59–09:20
	Autumn	Evening	Before	Light			
			After	Dark	16:58–18:01	18:58–20:01	14:58–16:01
2007	Spring	Morning	Before	Light			
			After	Dark	06:03–06:10	04:03–04:10	08:03–08:10
	Spring	Evening	Before	Dark			
			After	Light	18:47–19:40	20:47–21:40	16:47–17:40
	Autumn	Morning	Before	Dark			
			After	Light	06:55–07:16	04:55–05:16	08:55–09:16
	Autumn	Evening	Before	Light			
			After	Dark	17:05–17:55	19:05–19:55	15:05–15:55
2008	Spring	Morning	Before	Light			
			After	Dark	05:55–06:00	03:55–04:00	07:55–08:00
	Spring	Evening	Before	Dark			
			After	Light	18:57–19:55	20:57–21:55	16:57–17:55
	Autumn	Morning	Before	Dark			
			After	Light	06:50–07:15	04:50–05:15	08:50–09:15
	Autumn	Evening	Before	Light			
			After	Dark	17:00–18:02	19:00–20:02	15:00–16:02
2009	Spring	Morning	Before	Light			
			After	Dark	06:03–06:04	04:03–04:04	08:03–08:04
	Spring	Evening	Before	Dark			
			After	Light	18:50–19:50	20:50–21:50	16:50–17:50
	Autumn	Morning	Before	Dark			
			After	Light	06:50–07:15	04:50–05:15	08:50–09:15
	Autumn	Evening	Before	Light			
			After	Dark	17:09–18:10	19:09–20:10	15:09–16:10
2010	Spring	Morning	Before	Light			
			After	Dark	05:59–06:10	03:59–04:10	07:59–08:10
	Spring	Evening	Before	Dark			
			After	Light	18:50–19:38	20:50–21:38	16:50–17:38
	Autumn	Morning	Before	Dark			
			After	Light	06:59–07:30	04:59–05:30	08:59–09:30
	Autumn	Evening	Before	Light			
			After	Dark	17:00–17:57	19:00–19:57	15:00–15:57

(continued)

Appendix 1 Continued

Year	Season	Time of day	Period	Light condition	Case control window	Dark control window	Day control window
2011	Spring	Morning	Before	Light			
			After	Dark	05:56–06:26	03:56–04:26	07:56–08:26
	Spring	Evening	Before	Dark			
			After	Light	18:52–19:42	20:52–21:42	16:52–17:42
	Autumn	Morning	Before	Dark			
			After	Light	07:00–07:20	05:00–05:20	09:00–09:20
	Autumn	Evening	Before	Light			
			After	Dark	17:00–18:00	19:00–20:00	15:00–16:00
2012	Spring	Morning	Before	Light			
			After	Dark	06:10–06:21	04:10–04:21	08:10–08:21
	Spring	Evening	Before	Dark			
			After	Light	18:40–19:40	20:40–21:40	16:40–17:40
	Autumn	Morning	Before	Dark			
			After	Light	06:57–07:21	04:57–05:21	08:57–09:21
	Autumn	Evening	Before	Light			
			After	Dark	17:05–18:00	19:05–20:00	15:05–16:00
2013	Spring	Morning	Before	Light			
			After	Dark	05:50–6:15	03:50–04:15	07:50–08:15
	Spring	Evening	Before	Dark			
			After	Light	18:55–19:47	20:55–21:47	16:55–17:47
	Autumn	Morning	Before	Dark			
			After	Light	06:58–07:26	04:58–05:26	08:58–09:26
	Autumn	Evening	Before	Light			
			After	Dark	17:00–18:00	19:00–20:00	15:00–16:00
2014	Spring	Morning	Before	Light			
			After	Dark	05:55–06:05	03:55–04:05	07:55–08:05
	Spring	Evening	Before	Dark			
			After	Light	18:50–19:45	20:50–21:45	16:50–17:45
	Autumn	Morning	Before	Dark			
			After	Light	06:50–07:15	04:50–05:15	08:50–09:15
	Autumn	Evening	Before	Light			
			After	Dark	17:07–18:03	19:07–20:03	15:07–16:03
2015	Spring	Morning	Before	Light			
			After	Dark	05:55–06:08	03:55–04:08	07:55–08:08
	Spring	Evening	Before	Dark			
			After	Light	18:53–19:50	20:53–21:50	16:53–17:50
	Autumn	Morning	Before	Dark			
			After	Light	06:45–07:45	04:45–05:45	08:45–09:45
	Autumn	Evening	Before	Light			
			After	Dark	17:12–18:18	19:12–20:18	15:12–16:18

Note: These windows are defined by the earliest and latest RTC occurring in the case periods for each year that met the inclusion criteria.