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RESEARCH ARTICLE

Variance in Odds Ratios for Estimating the Deterrent Effect of Darkness on Cycling: The Influence of Journey Type

Jim Uttley, Demet Yesiltepe, Maan Balela and Steve Fotios
School of Architecture and Landscape, University of Sheffield, UK
Corresponding author: Demet Yesiltepe (d.yesiltepe@sheffield.ac.uk)

Odds ratios can be used to measure the deterrent effect of darkness on cycling by comparing the number of cyclists in case and control hours. In this work, we investigate the variance in odds ratios associated with different types of cycling journeys, whether utilitarian or recreational, contrasting weekday and weekend cyclists counts as a proxy for the type of journey. This was done for counts of cyclists recorded in five cities—Arlington (VA, USA), Bergen (Norway), Berlin (Germany), Birmingham, and Leeds (UK). The results suggest that darkness has a greater impact on recreational cycling than on utilitarian cycling, a similar distinction to that reported for the effect of weather. We also show that variation in the proportions of utilitarian and recreational cycling journeys at different times of the day explains variance in the odds ratios established for all possible combinations of case and control hours.

Keywords: cycling; travel flow; darkness; odds ratio; journey type

1. Introduction

A first step in investigating the potential beneficial application of road lighting is to explore the effect of differences in ambient light level—typically between daylight and darkness—on outdoor events. This approach has been done in investigations of road traffic collisions (Sullivan and Flannagan, 2002, 2007; Johansson, Wanvik and Elvik, 2009; Uttley and Fotios, 2017a; Raynham *et al.*, 2019; Robbins and Fotios, 2020), crime (Doleac and Sanders, 2015; Domínguez and Asahi, 2019; Fotios, Robbins and Farrall, 2021, 2022), and traffic flow (Uttley and Fotios, 2017b; Fotios and Robbins, 2022; Wessel, 2022).

The focus of the current work is cycling and the degree to which darkness deters cycling, and hence the potential mitigation offered by road lighting. In previous works (Fotios, Uttley and Fox, 2019; Uttley, Fotios and Lovelace, 2020; Uttley *et al.*, 2023), the numbers of cyclists in daylight and darkness were compared at the same time of day, using an odds ratio (OR) (Szumilas, 2010) to compare those data with parallel control periods where the ambient light level does not change, thus intending to isolate the effect of change in ambient light level from other temporal changes, such as the weather. The OR found in those studies suggested statistically significant departures above an OR of 1.0, indicating a significant deterrent effect of darkness on cycling. To interpret effect sizes, thresholds of 1.22, 1.86, and 3.00 for small, medium, and large effect sizes (Cohen, 1992; Olivier and Bell, 2013) were used with the assumption that these represent the minimum threshold for the stated effect size. The estimated ORs for cyclist flows varied from 1.05, indicating a negligible effect, to 1.67, indicating a small effect.

A limitation of those previous studies (Fotios, Uttley and Fox, 2019; Uttley, Fotios and Lovelace, 2020; Uttley *et al.*, 2023) is that they each used only one case hour (18:00–18:59) and only two control hours—one in daylight and one in darkness. There are many more possible case hours and control hours that could be used, and hence many more possible combinations of case and control hour. At different times of day, the numbers of cyclists and the reason for cycling changes (Miranda-Moreno *et al.*, 2013; Wessel, 2020). There are also differences in light level within the ambient light level categories of daylight and darkness, rather than these being strictly dichotomous. This raises the question of the degree to which the choice of case and control hours matters. That was explored in recent work (Fotios *et al.*, 2024) in which ORs were calculated for all combinations of possible case and control hour for five cities. **Table 1** shows the lower and upper OR estimates for each city found in that range of case and control hours. As expected, the ORs varied. For example, in Arlington (Virginia, USA), the two possible case hours and 15 possible control hours give 30 combinations, for which the ORs ranged from 0.97 to 3.60. To establish an OR for any one city, a weighted mean OR was used, in which the OR for each specific combination of case hour and control hour was weighted by the number of cyclists in those periods following the Mantel-Haenszel method (Mantel and Haenszel, 1959; Silcocks, 2005).

For Arlington (29 out of 30 cases), Birmingham (all 50 cases), and Leeds (56 of 60 cases), the ORs were significantly greater than 1.0 in 135 of the 140 cases, while in the remaining five cases the ORs were not suggested to depart significantly from 1.0 (Fotios *et al.*, 2024). The ORs suggest an effect exceeding the threshold for at least a small effect in 100 cases.

For the remaining two cities (Bergen and Berlin), the results were mixed. Of the 90 combinations of case and control hour, the OR was significantly greater than 1.0 in 49 cases, not significantly different from 1.0 in five cases, and significantly less than 1.0 in 36 cases. The latter finding indicates a relative increase in cycling after dark, an unexpected finding given that darkness is stated to be one reason for not cycling (Winters *et al.*, 2011; Pearson *et al.*, 2023).

Table 1: Odds Ratios (OR) for the effect of darkness on cyclist numbers as reported in previous studies using the whole year method of analysis (Fotios *et al.*, 2024).

City	Data range	No. of counters	No. of case hour × control hour combinations	Odds Ratios		
				Lowest OR	Highest OR	Weighted mean OR
Arlington, VA, US	01/2012 to 12/2015	24	30	0.97	3.60	1.80
Bergen, Norway	01/2016 to 12/2019	15	40	0.71	1.42	1.01
Berlin, Germany	01/2016 to 12/2019	26	50	0.77	1.41	1.16
Birmingham, UK	01/2012 to 12/2015	43	50	1.18	2.68	1.56
Leeds, UK	01/2012 to 12/2019	23	60	1.01	1.48	1.18

Possible explanations for this variation include weather conditions and journey types. Several studies have reported that cyclists prefer to avoid cycling in adverse weather (Bergström and Magnusson, 2003; De Witte *et al.*, 2013; Böcker, Dijst and Faber, 2016; Rérat, 2019). We consider two types of journey, utilitarian and recreational (Miranda-Moreno *et al.*, 2013; Wessel, 2020), and it has been demonstrated that the deterrent effect of weather is stronger for recreational journeys than for utilitarian journeys (Zhao *et al.*, 2018; Wessel, 2020). This may be because, for recreational journeys, cyclists have more flexibility to adjust their cycling time based on weather conditions than for utilitarian journeys: recreational trips are more flexible and can be cancelled or postponed to a time when the weather is likely to be better.

In the current article we extend previous work to explore whether the journey type also explains variance in the deterrent effect of darkness. Given that utilitarian cyclists are more resilient to bad weather and more likely to cycle than recreational cyclists (Hanson and Hanson, 1977; Thomas, Jaarsma and Tutert, 2013; Zhao *et al.*, 2018; Wessel, 2020), it was hypothesized that utilitarian journeys such as commuting are less likely to be deterred by darkness than are recreational journeys.

The data used in these analyses are cyclist counts captured by automated counters. These counters do not distinguish between utilitarian and recreational journeys. We suggest, however, that separating weekday and weekend data provides a reasonable proxy for utilitarian and recreational cycling journeys. This is because, in developed nations, people are more likely to attend employment on weekdays and be off work on weekends (US Bureau of Labor Statistics, 2023). **Figure 1** shows the number of cyclists per hour on weekend days and weekdays for the five cities reported in **Table 1**. Weekdays display a bimodal distribution with peaks located in periods associated with morning and evening commuter traffic. Weekends display a unimodal distribution centered around the middle of the day.

Previous studies have also distinguished between weekday and weekend cyclist numbers as a proxy for utilitarian and recreational cycling journeys (Miranda-Moreno *et al.*, 2013; Wessel, 2020). We therefore established separate ORs for cyclist counts on weekdays and weekends with the assumption that this would provide a reasonable estimate of how darkness deters cycling differently for utilitarian and recreational cycling journeys.

2. Method

ORs describing the impact of darkness on cyclist numbers were determined for the five cities (Arlington, Bergen, Berlin, Birmingham, and Leeds) used in previous work (Fotios *et al.*, 2024).

2.1 Data sources

This analysis used the number of cyclists passing a specific location as recorded by automated counters installed by organizations such as local authorities seeking to monitor traffic flow. Other than for Arlington, the data are available only at hourly intervals, and hence analyses were conducted using one-hour time windows. **Table 2** shows the data sources, the number of counters at each location, and the ranges for which data were analysed. For all five cities, the data were available to the public.

Following our previous work (Fotios *et al.*, 2024), the current analysis used, as closely as possible, the same data as the original analyses shown in **Table 1**. This meant data for the four years from 2012 to 2015 (i.e., beginning of 2012 to end of 2015) in Birmingham and Arlington, and four years in Bergen from 2016 to 2019. Despite the availability of data for

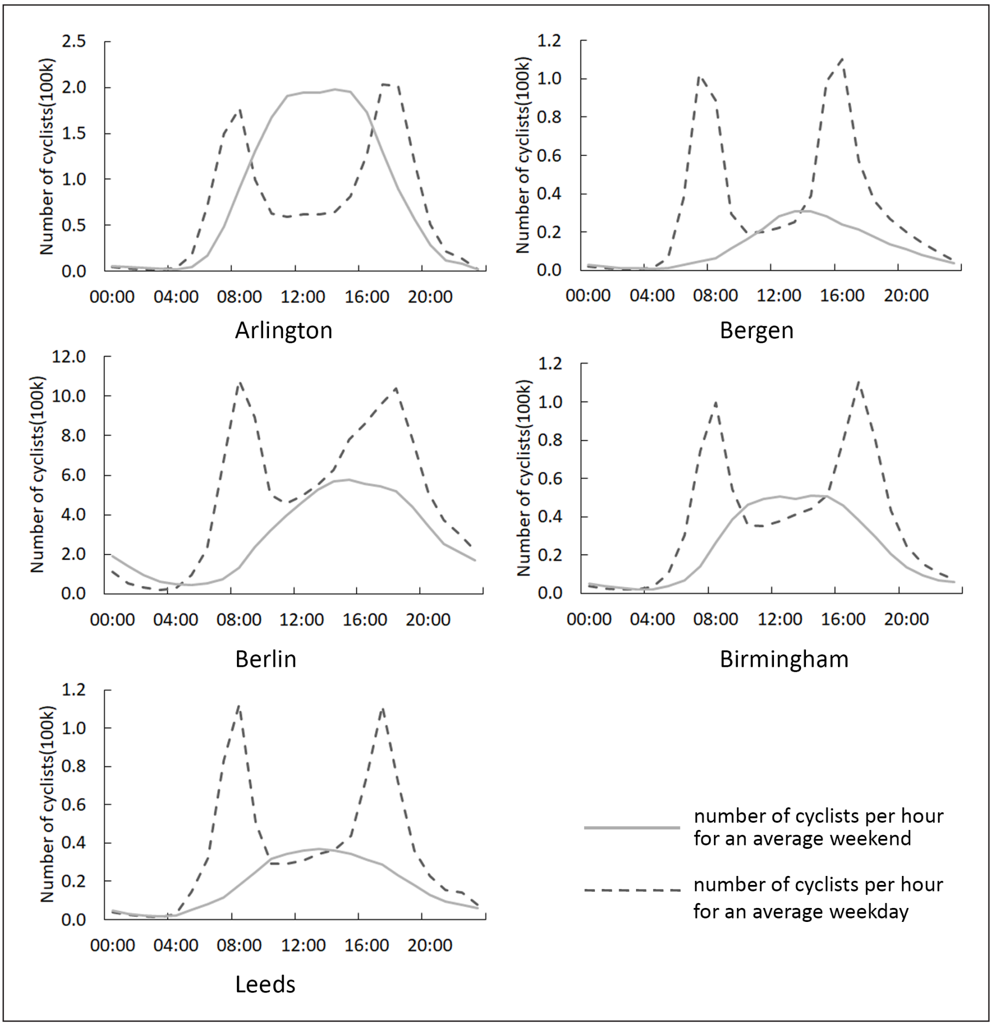

Figure 1: The number of cyclists per hour for an average weekend day and weekday. These are data for **(a)** Arlington (2012–2015), **(b)** Bergen (2016–2019), **(c)** Berlin (2016–2019), **(d)** Birmingham (2012–2015), and **(e)** Leeds (2012–2019).

additional years since the previous work, these were omitted for consistency and comparability with the previous work. For the two new locations, the data were for eight years in Leeds (2012–2019) and four years in Berlin (2016–2019). This represents the onset of data availability but stops at the end of 2019 to avoid any confounds caused by including 2020—the year in which travel restrictions were imposed due to the Covid-19 pandemic. An additional criterion for the current analysis was that counter data were retained only for complete years. This meant that for a counter installed (or removed) partway through a year, that part-year of data were omitted, but subsequent complete years were retained. The cycle counters in Arlington recorded inbound and outbound information separately at the same location; this analysis used the sum of inbound and outbound cyclists to determine the total number of cyclists.

Table 2: Sources and extent of automated cycle count data.

Location	Latitude (°)	Number of counters	Date range	Data source
Arlington, VA, USA	38.88	24	01/2012 to 12/2015	https://counters.bikearlington.com/data-for-developers/ (Bike Arlington, 2014)
Bergen, Norway	60.39	15	01/2016 to 12/2019	https://trafikkdata.atlas.vegvesen.no/ (Statens vegvesen, no date)
Berlin, Germany	52.52	26	01/2016 to 12/2019	https://www.berlin.de/sen/uvk/mobilitaet-und-verkehr/verkehrsplanung/radverkehr/weitere-radinfrastruktur/zaehlstellen-und-fahrradbarometer/ (Berlin Department for Mobility Transport Climate Protection and the Environment, 2023)
Birmingham, UK	52.48	43	01/2012 to 12/2015	https://data.birmingham.gov.uk/dataset/cycling-sensors (Birmingham City Council, 2019)*
Leeds, UK	53.80	23	01/2012 to 12/2019	https://datamillnorth.org/dataset/leeds-annual-cycle-growth- (Data Mill North, 2023)

*At the time of writing, this database was not available online: we used a version previously downloaded.

2.2 Procedure

All possible darkness and daylight periods were defined according to data collected from the Time and Date website (Timeanddate, 2023). These data provide times of daily sunrise and sunset (solar altitude 0°) and the transition from civil to nautical twilight (solar altitude –6°). *Case* hours were those that were in daylight (solar altitude > 0°) for one part of the year and in darkness (solar altitude < –6°) for another part. We excluded dates where the case hours included any period in civil twilight (according to the data available, there could be inclusion of up to one minute of civil twilight). We also excluded case hours for which the period of daylight or darkness was less than two months, to ensure that the data included was representative and not skewed by any anomalous occurrences or events that may otherwise exert a significant influence over a relatively short period of cycle count data. *Control* hours were those that were either in daylight (solar altitude > 0°) or darkness (solar altitude < –6°) for the entirety of the year. If an hour contained a minute or more of civil twilight (0° ≥ solar altitude ≥ –6°), it was not included as a control hour.

Following the application of these selection criteria, the number of included case hours ranged between two (Arlington) and eight (Bergen), and the number of included control hours ranged between five (Bergen) and 15 (Arlington). The selections of case and control hours for each location are shown in **Table 3**. Note that Bergen does not have any control hours in the evening/early morning due to the long periods of daylight in the summer, resulting in any evening/early morning hour containing some amount of civil twilight. Note also that Arlington does not have any case hours in the morning due to minimal differences between sunrise times in the summer and winter.

We use the term "darkness" according to the definition of changes in ambient light level, as defined by Muneer, according to solar altitude (Muneer, 1997). Darkness, therefore, means

Table 3: Case and control hours included in analysis by location.

Location	Case hours	Control hours
Arlington	18:00–18:59, 19:00–19:59	00:00–00:59, 01:00–01:59, 02:00–02:59, 03:00–03:59, 04:00–04:59, 08:00–08:59, 09:00–09:59, 10:00–10:59, 11:00–11:59, 12:00–12:59, 13:00–13:59, 14:00–14:59, 15:00–15:59, 22:00–22:59, 23:00–23:59
Bergen	05:00–05:59 ,06:00–06:59, 07:00–07:59, 17:00–17:59, 18:00–18:59, 19:00–19:59, 20:00–20:59, 21:00–21:59	10:00–10:59, 11:00–11:59, 12:00–12:59, 13:00–13:59, 14:00–14:59
Berlin	06:00–06:59, 17:00–17:59, 18:00–18:59, 19:00–19:59, 20:00–20:59	00:00–00:59, 01:00–01:59, 02:00–02:59, 09:00–09:59, 10:00–10:59, 11:00–11:59, 12:00–12:59, 13:00–13:59, 14:00–14:59, 23:00–23:59
Birmingham	06:00–06:59, 17:00–17:59, 18:00–18:59, 19:00–19:59, 20:00–20:59	00:00–00:59, 01:00–01:59, 02:00–02:59, 09:00–09:59, 10:00–10:59, 11:00–11:59, 12:00–12:59, 13:00–13:59, 14:00–14:59, 23:00–23:59
Leeds	05:00–05:59, 06:00–06:59, 17:00–17:59, 18:00–18:59, 19:00–19:59, 20:00–20:59	00:00–00:59, 01:00–01:59, 02:00–02:59, 09:00–09:59, 10:00–10:59, 11:00–11:59, 12:00–12:59, 13:00–13:59, 14:00–14:59, 23:00–23:59

the absence of daylight. It is, of course, possible that the locations of some automated counters were lit after dark by electric lighting, but that was not considered in the current work.

For each counter, the counts for each hour were checked for the presence of missing or negative values, indicating a fault in the counter's operation. In those cases where such values were found, the numbers for that period were removed from the corresponding control or case hours. The extent of missing data ranged from approximately 1% (Leeds) to approximately 12% (Berlin).

The effect of ambient light level on cyclist numbers was revealed using the OR defined in Equation 1. This compares the numbers of cyclists in the daylight and dark periods of the case hour with the number of cyclists in the control hour for the same times of year. An OR > 1.0 shows that cyclist numbers are reduced in darkness, while an OR = 1.0 shows that cyclist numbers were not affected by ambient light level. Additionally, ORs are calculated for weekdays and weekends by categorizing the count dates and separating them into weekdays and weekends using the weekday function in Excel.

$$R_{\text{odds}} = \frac{(A/B)}{(C/D)} \tag{1}$$

Where

R_{odds} is the odds ratio (OR)
A is the number of cyclists when the case hour is in daylight
B is the number of cyclists when the case hour is in darkness
C is the number of cyclists in the control hour when the case hour is in daylight
D is the number of cyclists in the control hour when the case hour is in darkness

In any given city, there are multiple possible combinations of case and control hour **(Table 2)**. A weighted mean OR was established, where the weighting factor was determined by the numbers of cyclists in the case and control hours for each specific OR. This approach, shown in Equation 2, is based on the Mantel-Haenszel method (Mantel and Haenszel, 1959; Silcocks, 2005). Ninety-five percent Confidence Intervals (95% CI) for the weighted OR were calculated using the Robins, Breslow, and Greenland method (*V*) as shown in Equations 3 and 4 (Silcocks, 2005).

$$MH_{\text{w-odds}} = \frac{\sum \frac{AD}{N}}{\sum \frac{BC}{N}} \tag{2}$$

Where
$MH_{\text{w-odds}}$ is Mantel-Haenszel pooled OR
N is the total number of cyclists in case and control hours (A+B+C+D)
A, B, C, D are defined as for Equations 1

$$95\%\ CI = exp(ln(MH_{\text{w-odds}}) + 1.96\sqrt{V}) \tag{3}$$

where

$$V = \frac{\sum RP}{2R^2} + \frac{\sum (PS + QR)}{2RS} + \frac{\sum SQ}{2S^2} \tag{4}$$

Here,
P is calculated as ((A+D)/N)
Q is calculated as ((B+C)/N)
R is calculated as ((AD)/N)
S is calculated as ((BC)/N)

3. Results

Table 4 and **Figure 2** show the weighted mean OR for each city for the weekend and weekday counts of cyclists. The ORs found for each combination of case and control hour are shown in Table S1, and the aggregated count data are shown in Table S2. In all cases, the weighted mean ORs are suggested to be significantly greater than 1.0, indicating a relative reduction in cycling after dark.

In all five cities, the OR for weekend travel is greater than that for weekday travel, signifying a more substantial detrimental impact of darkness on cyclist numbers during weekends. Within any city, the 95% CIs for weekends and weekdays do not overlap, which suggests a significant difference (Cumming, 2009). Assuming that a comparison of weekends versus weekdays is a sufficient proxy for a comparison of recreational versus utilitarian cycling journeys, these data suggest that darkness has a greater deterrence effect on cycling for recreational journeys than for utilitarian journeys.

Weekend ORs exceed the threshold for a small effect size in all five cities, and further exceed the threshold for a medium effect size in Birmingham and a large effect size in Arlington. Weekday ORs exceed the threshold for a small effect size in only three cities, being a small effect in Leeds and Birmingham and a medium effect in Arlington, but the effect size is negligible in Bergen and Berlin.

Table 4: The weighted mean ORs ($MH_{w\text{-}odds}$), 95%CIs, and effect sizes for each city for the weekday and weekend periods. In each case, the OR departs significantly from 1.0 ($p < 0.001$).

City	Part of the week	$MH_{w\text{-}odds}$	95% CI of $MH_{w\text{-}odds}$ (lower)	95% CI of $MH_{w\text{-}odds}$ (upper)	Effect size
Arlington	Weekday	1.87	1.87	1.88	Medium
	Weekend	3.50	3.48	3.53	Large
Bergen	Weekday	1.01	1.01	1.02	Negligible
	Weekend	1.30	1.29	1.31	Small
Berlin	Weekday	1.15	1.15	1.15	Negligible
	Weekend	1.32	1.32	1.32	Small
Birmingham	Weekday	1.53	1.53	1.53	Small
	Weekend	2.08	2.06	2.09	Medium
Leeds	Weekday	1.22	1.21	1.22	Small
	Weekend	1.25	1.24	1.25	Small

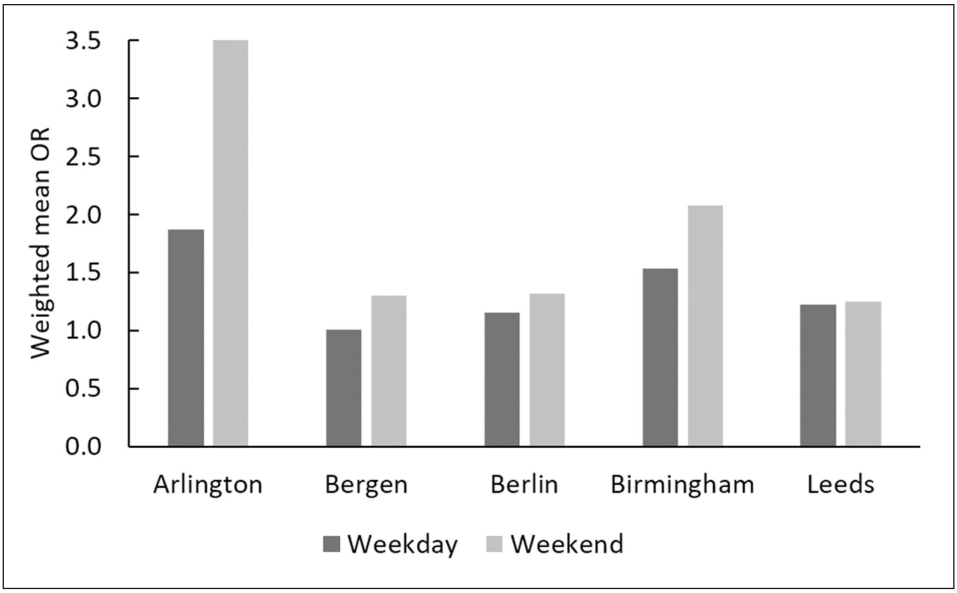

Figure 2: Weighted mean ORs for the effect of darkness on cycle flows, for weekend and weekday counts of cyclists in five cities. CIs are shown in **Table 4**.

4. Impact of Journey Type

Having suggested that the deterrent effect of darkness is different for recreational and utilitarian journeys, this raises a further issue. Using a case and control method to investigate the effect of different conditions of ambient light on cycling rates assumes that this isolates the effect of ambient light level from other changes that might influence the number of people cycling, such as changes in weather conditions. However, if the proportions of recreational and utilitarian cycling journeys differ for the case and control periods, then the current analysis suggests that such differences would confound the case/control method.

Our previous work (Fotios *et al.*, 2024) found that some combinations of case and control hour yielded an OR significantly below 1.0, in particular where the case hour was in the morning. This intuitively sounds implausible, as it suggests darkness encourages, rather than deters, cycling. Our current analysis offers an explanation for this variance in the proportion of utilitarian and recreational cyclists in any given hour. This can lead to ORs below 1.0 if the proportion of utilitarian cyclists in the case hour is notably higher than the proportion of utilitarian cyclists in the control hour. This is because the effect that ambient light and weather conditions have on the decision to cycle will vary in magnitude between utilitarian and recreational cyclists. Previous evidence has shown that poor weather conditions are more likely to deter recreational cyclists than utilitarian cyclists (Thomas, Jaarsma and Tutert, 2013). We can also assume that recreational cyclists are more likely to be deterred from cycling by darkness than utilitarian cyclists, as is suggested by our weekend versus weekday analysis.

We use the control hour to account for increases in cycling in summer months due to better weather, and anticipate that the relative increase in cyclists in the case hour will be larger than in the control hour because it includes the benefits of both daylight and better weather, thus producing an OR greater than 1.0. However, if the effect of better weather in the control hour is larger than the combined effects of both better weather and daylight in the case hour, it becomes possible to obtain an OR below 1.0. This is most likely to occur when there is a high proportion of recreational cyclists in the control hour, whose numbers are likely to increase significantly in the summer in response to the better weather, and a high proportion of utilitarian cyclists in the case hour, whose numbers will increase in the summer but not as significantly because they are less influenced by improvements in weather and ambient light conditions.

These hour-dependent variations in the seasonal cycle count fluctuations can be seen in **Figure 3**, which shows the monthly cycle counts for three example hours in one city, Bergen. This illustrates the anticipated seasonal fluctuation in cycle counts, with increases in all three hours during the summer months. However, the increase from winter months to summer months is larger for the hour of 19:00, which is a case hour, compared with 12:00, which is a control hour. This can be explained by the fact that 19:00 includes the effects of both improved weather and a shift from darkness to daylight, whereas 12:00 only includes the effect of improved weather. In contrast to this, the hour of 06:00, which is also a case hour, does not show such a large increase in cycle counts from winter to summer months, despite it including the effects of improved weather and the shift from darkness to daylight. Such a situation has the potential to produce an OR below 1.0.

Such a circumstance is most likely to occur for morning case hours. That is because morning case hours tend to have higher percentages of utilitarian cyclists than do evening case hours, as can be seen in the data from the UK National Travel Survey **(Figure 4)**. Morning hours before 09:00 have higher percentages of utilitarian trips than do evening "commuter" hours between 15:00 and 19:00.

We suggest that variations in the proportions of utilitarian and recreational cyclists between case and control hours introduce a confound into the OR method, and can explain why ORs below 1.0 can sometimes be observed for certain case and control hour combinations, usually if the case hour is in the morning. Our previous results (Fotios *et al.*, 2024) show that morning case hours generally produce lower ORs than evening case hours: our explanation for this is that morning case hours will have higher proportions of utilitarian cyclists than evening case hours. Data from the UK National Travel Survey **(Figure 4)** suggests that there

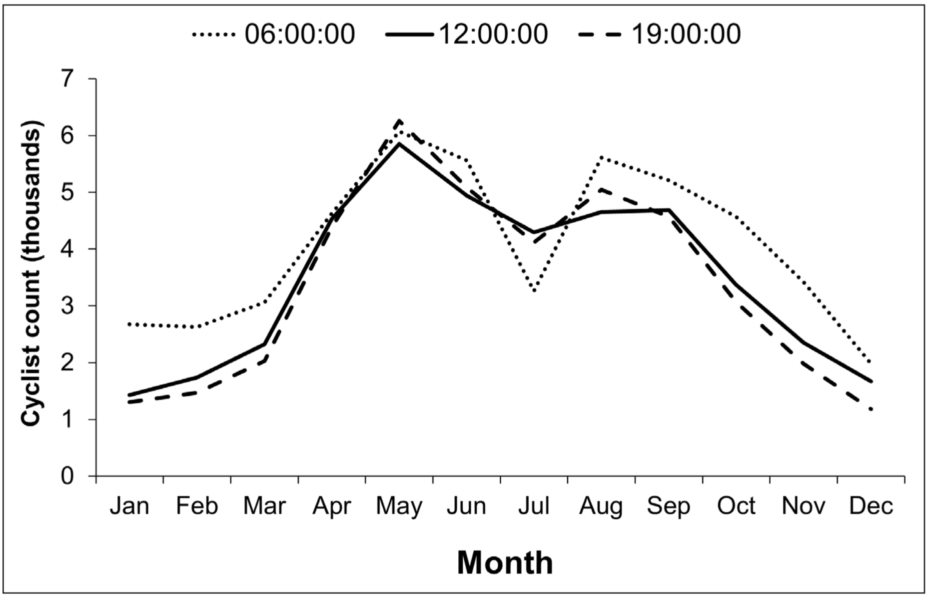

Figure 3: Monthly cycle counts in Bergen, averaged across all years, for two case hours (06:00–06:59 and 19:00–19:59) and one control hour (12:00–12:59).

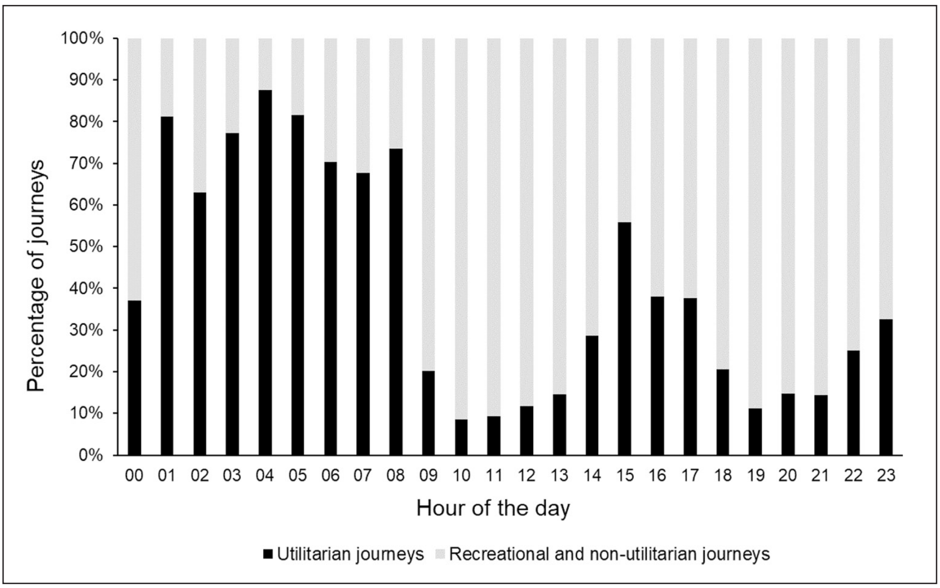

Figure 4: Percentages of utilitarian journeys and recreational and non-utilitarian journeys by hour of the day, for weekdays in England. Data for 2022 from the UK National Travel Survey data table NTS0502 (Department for Transport, 2023). The "utilitarian journeys" category here was created by combining the journey purpose categories of commuting, business, education, and escort education. The "recreational and non-utilitarian journeys" category here was created by combining all other journey purpose categories: shopping; other work, other escort, and personal business; visiting friends, entertainment, and sport; holiday, day trip and other.

is a large mismatch in the percentage of utilitarian cyclists for a case hour starting at 06:00 (70% of journeys are utilitarian) and a control hour starting at 12:00 (12% of journeys are utilitarian). We can anticipate that this combination of case and control hours might produce a particularly low OR, compared with a combination of case and control hours that have similar percentages of utilitarian journeys, such as a case hour starting at 19:00 (11% of journeys are utilitarian) paired with a control hour starting at 12:00. **Table 5** compares the OR for these two pairings of case and control hours for four cities (Arlington is omitted as it does not have 06:00–06:59 as case hour). The ORs are consistently higher for the case hour starting at 19:00 than for the case hour starting at 06:00. We suggest this trend is caused by the 06:00 case hour having a significantly higher proportion of utilitarian journeys than the control hour, but the 19:00 case hour having a similar proportion of utilitarian journeys to the control hour.

Further evidence that variations in the percentage of utilitarian journeys between the case and control hour can explain variations in ORs between different case and control hour combinations can be seen in **Figure 5**. This plots the weekend and weekday ORs for each case and control hour combination in one city (Birmingham) against the ratio of utilitarian journeys between case and control hour. For example, based on the National Travel Survey data, the hour of 06:00–06:59 (a case hour) has 70% utilitarian journeys. In the hour of 09:00–09:59 (a control hour), 20% of journeys are utilitarian. This would give a case/control ratio of 3.5 (70% divided by 20%). **Figure 4** shows that as this ratio increases, the OR decreases. Lower ORs are expected (i.e., approaching 1.0) when the percentage of utilitarian journeys is much higher in the case hour than the control hour. Higher ORs are expected (i.e., departing further from 1.0) when the percentage of utilitarian journeys in the case hour is similar to or less than in the control hour. The ratio of utilitarian journeys between the case and control hours explains a high proportion of the variance in the ORs, with an R^2 value of 0.69 for weekend ORs and 0.65 for weekday ORs (using logarithmic regression).

Using all possible combinations of case and control hours helps to overcome the confound that is introduced to the OR method by disparities in the proportion of utilitarian and recreational cyclists in case and control hours. The influence of this confound is potentially significant if only one or a small number of case and control hour combinations are used.

Table 5: Comparison of ORs obtained when using a case hour that has a much higher proportion of utilitarian journeys than the control hour (06:00–06:59) or a case hour that has a similar proportion of utilitarian journeys to the control hour (19:00–19:59). Note that the control hour used here is daylight.

City*	Part of the week	Case hour: 06:00–06:59 Control hour: 12:00–12:59	Case hour: 19:00–19:59 Control hour: 12:00–12:59
Bergen	Weekday	0.70	1.24
	Weekend	0.85	1.35
Berlin	Weekday	1.04	1.17
	Weekend	0.87	1.40
Birmingham	Weekday	1.21	1.70
	Weekend	1.21	2.14
Leeds	Weekday	1.19	1.25
	Weekend	0.98	1.26

*Arlington is not included as it does not have 06:00–06:59 as a case hour.

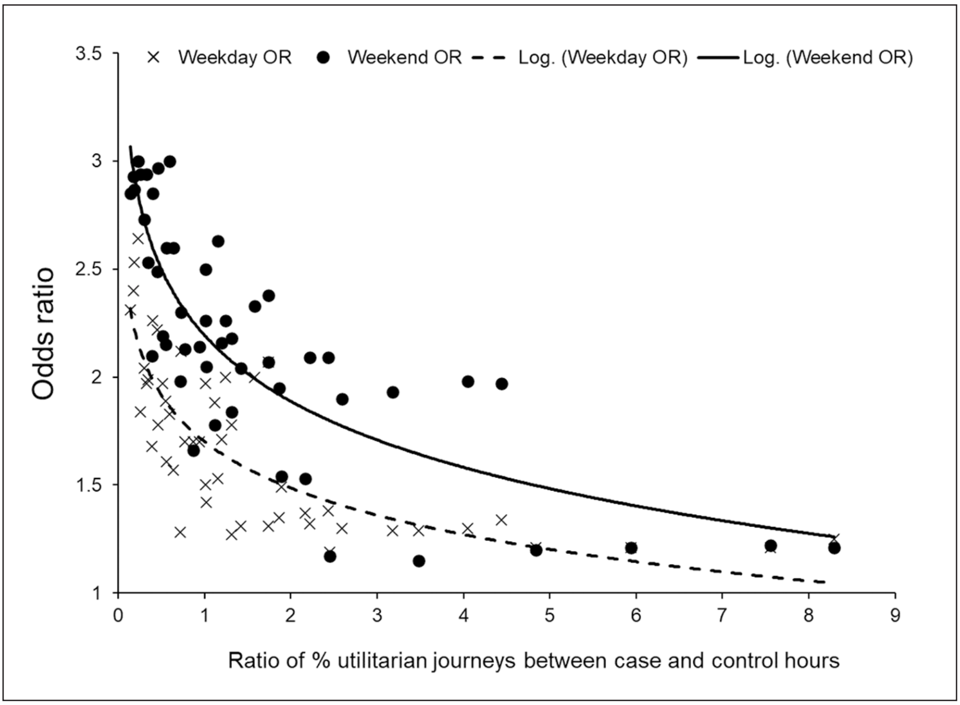

Figure 5: Weekend and weekday ORs for all case and control hour combinations in Birmingham, plotted against the ratio of the percentage of utilitarian journeys in the case hour to the percentage of utilitarian journeys in the control hour. Data for these percentages were obtained from the UK National Travel Survey data, NTS0502, for 2022 (Department for Transport, 2023). Logarithmic regression trend lines are shown.

However, calculating a Mantel-Haenszel pooled OR helps limit the influence of the confound by utilizing all possible combinations of case and control hours.

5. Conclusion

The aim of this study was to investigate whether darkness produces a similar deterrence on recreational and utilitarian cycling journeys. This was done by examining the weighted mean ORs established across all possible combinations of case and control periods from counts of cyclists in five cities.

It was assumed that weekday cycling is dominated by utilitarian journeys and weekend cycling by recreational journeys, and that recreational journeys would be more likely to be deterred by darkness. This was confirmed by the data, which revealed higher ORs and thus a greater deterrence effect of darkness for the weekend journeys. This is consistent with previous research indicating that recreational cyclists are more affected by external conditions (Hanson and Hanson, 1977; Thomas, Jaarsma and Tutert, 2013). That assumption was made because automated counters record the presence of a cyclist but not the journey type. It is expected that some utilitarian journeys are made on weekends and some recreational journeys are made on weekdays, but identifying the journey type more precisely to account for this would require a further means of measurement for which data are not yet available. This assumption means that any observed differences between weekday and weekend cycling are interpreted as differences between utilitarian and recreational cycling, which may oversimplify actual travel behavior and introduce some bias if the assumed patterns do not fully hold.

A further limitation of using secondary data from automated counters is that we do not know the type, model, and maintenance status of the counters. If available, such data would enable comment on the accuracy and precision of the count data. However, assuming that any error would be consistent across the time of day and across the year, the case-control method used in this work means that any error would have a negligible impact on the findings.

An additional limitation to our work is a lack of data about the morphological and environmental context of the cycle routes that each of the counters included in our analysis were located in. Factors such as how well-lit a route is or how close to the city center or to residential areas it is may influence cycling behavior at those locations, potentially influencing the ORs that we found if these factors interact with the effect ambient light has on cycling. For example, if routes are well-lit, we could anticipate darkness to have less of a deterrent effect on cycling (Fotios, Uttley and Fox, 2019). In further work, we are investigating the mediating influence that such morphological and environmental factors may have on the effect of darkness on cycling.

Within the weekend and weekday periods, there is variation amongst the ORs for each case and control hour combination (Table S1). We demonstrate that these variations may partly be explained by variations in the percentage of utilitarian journeys made in the case and control hours. Other factors may also explain variations found in the ORs, and in further work, we establish the extent to which this variance in ORs can be explained by the spatial location of the cyclist counter, such as its distance from the city centre (Yesiltepe *et al.*, 2023).

Data Accessibility Statement

Raw data about cycle counts is publicly available, see **Table 2**. Processed and aggregated count data that has been used to produce the results in this paper are provided as supplementary Table S1 and Table S2.

Additional File

The additional file for this article can be found as follows:

- **Supplementary File.** Supplementary Table S1 and Table S2. DOI: https://doi.org/10.16997/ats.1790.s1

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Competing Interests

The authors have no competing interests to declare.

Author Contributions

JU: Conceptualization, funding acquisition, methodology, visualization, project administration, supervision, writing – original draft.
DY: Conceptualization, data curation, formal analysis, methodology, visualization, writing – original draft.
MB: Conceptualization, writing – review and editing.
SF: Conceptualization, funding acquisition, methodology, project administration, supervision, writing – original draft.

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