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The Effect of Lighting on Crime Counts

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Abstract: The influence of lighting on crime was investigated by considering the effect of ambient light level on crimes recorded in three US cities for the ten-year period 2010 to 2019. Crime counts were compared for similar times of day, before and after the biannual clock change, therefore employing an abrupt change of light level but without an obvious intervention such as improving road lighting in an area. The results suggest a significant increase in robbery during darkness, confirming previous studies. The results also suggest darkness leads to an increase in arson and curfew loitering offenses, and to a decrease in disorderly conduct, family offences (non-violent) and prostitution. Future research investigating the effectiveness of improved street lighting should consider that this may not be beneficial for all types of crime.

Keywords: lighting; crime; robbery

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1. Introduction

While there are many benefits arising from the provision of road lighting [1] its installation and use also brings unwanted consequences including light pollution, energy use and ecological impact. An aim of lighting design, and of recommended criteria for lighting design, should therefore be to balance the benefits and consequences.

One of the assumed benefits of road lighting in subsidiary roads is a reduction in crime. For example, the benefits of road lighting described in BS5489-1:2020 [2] include "the potential of helping to reduce crime" and to "discourage crime against people and property." CIE 115:2010 [3] also suggests that good lighting "discourages crime against the person and property" and "makes the detection of crime easier"; furthermore, it states that "Residential lighting is, therefore, often installed or upgraded as a measure against crime and is assuming an increasing importance in this role, particularly in urban areas." An assumed benefit is not sufficient: in order to inform the cost–benefit equation of road lighting provision there needs to be robust evidence of where, when and what type(s) of crime are mitigated using road lighting.

Research on lighting and crime tends to consider the effect of improvements in lighting on crime rates in a local area. Typically, 'improvement' means either the illumination of a previously unlit road or an increase in the illuminance of a road which was already lit. There are two main theories of why such improvements may lead to a reduction in crime [4].

The first theory concerns the direct visual benefits of road lighting after dark. Improved lighting (specifically, a higher illuminance) increases acuity and reduces threshold contrast-it becomes easier to see items of smaller size and of lower contrast against their background [5]. Road lighting thus enables people to see more clearly at greater distances: it enables the law-abiding to take action, either assertive, preventive or avoidance, and exposes the criminal to greater public scrutiny [6]. The first theory is therefore that improved lighting leads to increased surveillance of potential offenders by improving their visibility to others. Lighting may also lead to an increase in people walking or cycling after dark [7–9], and hence surveillance of offenders is further supported by an increase in the number of people who might see them. According to the surveillance theory, improved lighting would result in decreased crime during the hours of darkness.

The second theory suggests that improved lighting signals community investment in the area and hence that the area is improving, leading to increased community pride, community cohesiveness, and informal social control [4]. This second theory predicts improved lighting would result in decreased crime during both daytime and after dark.

However, road lighting could also promote opportunities for crime [10]. An increase in walking or cycling after dark associated with improved (brighter) lighting [9] offers more victims and increased probability of interaction between victims and offenders [11]. Increased social activity outside the home may increase the number of unoccupied homes available for burglary. Increasing the visibility of offenders also increases the visibility of victims and property to offenders, offering a better judgement of their vulnerability and value.

Road lighting is not the only environmental factor associated with crime and indeed Boyce and Gutkowski [6] suggest that the role of lighting in crime prevention is limited. Factors associated with the road network such as travel time from the offender's home and familiarity with an area through routine passage have an influence on some types of crime: a burglar is more likely to target locations which are easier to reach and where they have an awareness of opportunities [12].

Welsh and Farrington [4] conducted a systematic review of evidence from 13 studies in the UK and the USA where improved road lighting was the main intervention. Their analysis used an odds ratio (their Relative Effect Size) to compare crime numbers, before and after installation of improved lighting, in test and control areas. It was concluded that road lighting significantly reduced crime, with an overall Relative Effect Size of 1.27 (95%CI 1.09–1.47, $p = 0.0008$) indicating that crime reduced by 21% in the test areas relative to that in the control areas. That should not be interpreted as a consistent effect: the overall reduction included three studies where crime increased after improved street lighting, although not to a degree which reached statistical significance. Welsh and Farrington [4] also found that night-time crimes did not decrease more than daytime crimes and from this concluded the data supported for the community pride theory rather than the increased surveillance theory. If a 21% reduction in crime was found to be a robust and generalizable estimate, this would aid the cost–benefit analysis of lighting provision.

Marchant [13] raised criticism of the statistical methods used in such reviews, in a paper referring to the previously published review by Farrington and Welsh [14]. One issue raised by Marchant was regression towards the mean [15]. The intervention, improved lighting, is usually installed in areas with an existing problem of high crime rather than the location(s) being randomly assigned and hence at the start of a trial will tend to be worse (a higher crime frequency) than control areas. Regression towards the mean describes the phenomenon that an initial extreme value will tend towards the average situation in further measurements: an area with high level of crime will tend towards a low level of crime regardless of the intervention, and will tend to decrease more than control areas which did not initially display a high level of crime.

Chalfin et al. [16] installed temporary lighting in 40 areas of New York city and found that this reduced outdoor night-time crimes by 36%. The test areas were those with high levels of crime, in particular violent crime, in which a survey found that "only 21 percent of public housing residents felt safe walking around their neighborhood at night, compared to 50 percent who felt safe during the daytime." However, the control areas were also those with high levels of crime: from an initial selection of 80 locations, all displaying high levels of crime, 40 were chosen at random and assigned as test areas and the remainder as control areas. Thus, any effect of regression toward the mean would similarly affect both the test and control areas. While these data indicate a crime reduction associated with lighting, the prominent nature of the temporary lighting towers and their allied generator may have contributed to the reduction rather than it being an effect of the lighting. It is also not known whether there was a parallel reduction in daytime crimes.

Steinbach et al. [17] investigated the effect on crime counts of four changes to road lighting made in the interest of energy saving; permanently switching off, reducing the number of hours switched on at night (part-night), reducing the output (dimming), and replacing the widely used (in the UK) sodium lamps for whiter light sources. While all four interventions involved local authority attention being given to the area, which might be expected to enhance community pride, switching-off, part-night and dimming might be seen as detrimental interventions, and the change to white lighting will lead to public complaints [18]. Data for their analysis were obtained from 62 (of 174) local authorities in England and Wales for the period December 2010 to December 2013. It was found that neither switching-off nor part-night strategies affected crime counts, but that there was weak (i.e., non-significant) evidence of a reduction in crime associated with white light and dimming strategies. Steinbach et al. [17] concluded that these results offered "little evidence of harmful effects" of energy saving measures. However, while a reduction in lighting may have had no adverse effects on crime (i.e., crime counts did not increase when lighting was switched off or dimmed), that does not necessarily imply that an increase in lighting would have led to a crime reduction: it depends on what was happening at the outset of the intervention.

'Improved' lighting tends to mean an increase in light levels. The interventions in the Steinbach et al. study (switching-off, part-night lighting and dimming) were reductions in light level: according to the surveillance theory, this should lead to an increase in crime (or, a reduction in benefit arising from the installed lighting). That Steinbach et al. found no effect with these strategies, or for dimming found a reduction in crime, does not follow the surveillance theory. The community pride theory suggests it is the local authority attention to an area that matters, not the change in lighting that was made, but in this case it is likely that the changes were noticeable and not appreciated by local residents, and hence community pride is unlikely to have been raised.

Davies and Farrington [19] raised limitations of Steinbach et al. [17], and supported this with a further study investigating the effect on crime of a part-night lighting strategy where lighting was switched off between 11:30 p.m. and 05:30 a.m. Four types of crime were considered: burglary, criminal damage, vehicle crime and violence (which included sexual offences and robbery). It was found that switching off road lighting was associated with increases in burglary and vehicle crime: there was no significant effect on criminal damage. Surprisingly, there was a decrease in violence, suggested to result from fewer pedestrians when the lighting was switched off.

An alternative approach to investigation of the relationship between light and crime is to consider the influence of changes in ambient light level (daylight vs. darkness) rather than changes in electric lighting. With such an approach there is no intervention, so no local authority activity to stimulate community pride, and any effect on crime can be attributed to changes in visibility.

Doleac and Sanders [11] explored the effect on crime in the USA of the shift in daylight following from the bi-annual daylight savings time (DST) clock changes, thus to reveal the cost effectiveness of DST clock changes. A one-hour clock change in spring moves an hour of available daylight from the morning to the evening through summer, and back to the morning through winter following the autumn clock change. Street crimes such as robbery and assault tend to occur more frequently in the evening than they in the morning when potential victims are at home and probably asleep, [20,21]. If the surveillance benefit of light is sufficient to deter crime, and if criminals maintain the same timetable before and after clock change, then DST clock change in Spring should reduce crime.

Doleac and Sanders considered four types of crime and found a 7% decrease ($p < 0.10$) in daily robbery and an 11% decrease ($p < 0.10$) in daily rape, in the weeks after onset of DST in the spring. Note that effects were suggested to be economically significant where $p < 0.10$. In both cases the overall decreases were attributed primarily to reductions in the evening twilight period (robbery; 27% decrease, $p < 0.05$, rape: 38% decrease, $p < 0.10$). Note also the authors' suggestion that the apparent significant reduction in rape was a result of outliers and not a real reduction. For the other two types of crime examined (aggravated assault and murder) there were no significant effects.

A limitation of Doleac and Sanders is that their data source represents mainly low-density and rural areas of the US. Hence, a subsequent study [22] investigating the impact of DST clock change on crime considered two metropolitan areas in Chile. For a two-hour evening period (7 p.m. to 9 p.m.) they compared crime frequency for four years (2005, 2006, 2007, 2009) in which a clock change occurred with two years (2008, 2010) in which it did not, for the spring clock change. It was found that crime decreased by 20% in those years where clock change was enacted giving the one-hour increase in evening daylight. Subsequent analysis by type of crime suggested that there was a significant effect on robbery but did not suggest a significant effect for other types of crime.

In summary, past studies suggest that improved lighting can lead to a reduction in the frequency of crime, with one meta-analysis [4] suggesting an overall reduction by 21%, but within such an overall reduction there might be areas where crime increases following improved lighting [4] and greater reductions have been reported [16]. One explanation for variations in the crime reduction effects of lighting is that some types of crime may be deterred more than others: it appears that improved surveillance is a particular deterrent for robbery [11,22] but less effective, if at all, for other types of crime.

Darkness induces a sense of anonymity [23] and concern about being caught may no longer be sufficiently salient to activate the behavioral inhibition system which would otherwise inhibit dishonest activity [24]. Robbery is an interpersonal crime, in which a criminal takes (or attempts to take) property directly from another person, where force may be used or threatened [25]. Robbery requires the criminal to get close to the victim before initiating the act. Eye tracking data show a tendency for pedestrians to look at other people, likely to assess their intent and identity, and these evaluations are enhanced by better lighting [26–28]. Being close to someone in better lighting increases the risk of identification: poor visual conditions such as darkness are thus of benefit to robbers and affect the risk calculus for robbery more than for crimes which do not involve close interpersonal proximity. A change in ambient light level is therefore not expected to affect burglary, which is also a theft but from property rather than directly from a person.

This article describes an investigation of ambient light level and crime. This extends previous studies by using a different method of analysis, the Odds Ratio (OR), by considering a wider range of crime types, and by considering the morning and evening daylight-dark transitions in both autumn and spring. The OR isolates the effect of changes in ambient light to compare crime frequencies for specific case windows in the seven-day periods before and after clock change with crime frequencies in control windows before and after clock change. The case windows are chosen so that it is daylight before clock change and dark afterwards (or vice versa, according to season and time of day). The control windows are chosen such that they remain either daylight or dark before and after the clock change. The aim of this approach is, therefore, to isolate the effect of ambient light level from other factors which may influence crime risk. Applying this method of analysis to different types of crime will reveal which, if any, are significantly influenced by change ambient light level. Such types of crime would therefore be deterred by the visibility benefit of improved road lighting.

This approach has been used in previous work investigating road traffic collisions (RTCs) [29–31] and traffic flow [7,9]. The current analysis uses the more precise method for isolating events as being in daylight or darkness as proposed by Raynham et al. [32]. This is a further requirement to the clock change method: an event was only considered to be within the case window if it occurred in darkness (a solar altitude of $<-6°$) for one week but also if it would be in daylight (a solar altitude of $\geq 0°$) 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).

2. Materials and Methods

Data for this analysis were drawn from the Crime Open Database (CODE) [33]. Specifically, this analysis used data from three cities, Austin, Chicago and Louisville for the ten-year period 2010 to 2019. These cities struggle with high crime rates, being 65% [34], 58% [35] and 84% [36] above the national average, respectively. The CODE database presents incident-level crime data for different cities, otherwise reported in multiple and incompatible formats, with harmonized geographic co-ordinates, dates and times, offense categories and location types, to allows the wider study of spatio-temporal patterns of crime [37]. The data thus include situational information on individual crime events such as the time, date, location (longitude and latitude), and details of the crime type.

In the CODE database, crimes are allocated into one of 32 types: arson, assault, bad cheques ('checks' in the original), burglary/breaking & entering, bribery, counterfeiting/forgery, curfew/loitering, destruction/vandalism of property, disorderly conduct, driving under the influence, drug offences, drunkenness, embezzlement, extortion/blackmail, family offences, fraud, gambling, homicide, human trafficking, kidnap/abduction, larceny/theft, liquor law violation, motor vehicle theft, peeping tom, pornography, prostitution, robbery, sex offences, stolen property, trespass of real property, weapon law offences and all other offences.

The data also provide details on crime location, with these being allocated into 13 types of location: commercial (construction, factory/warehouse, office), education (school. College, child-care), government, healthcare, hotel, leisure (bar/club, entertainment, restaurant), open space (green space), residence, retail (auto-dealer, convenience store, gas station, supermarket), street, transportation (airport, bus, paid transit), vehicle (commercial or private vehicle) and other. A particular type of crime could fall into one or more of these location categories depending on the specific crime.

The data analysis follows closely that used in previous work [30]. These data were filtered for crimes that occurred the week before and the week after the Spring and Autumn clock changes. This resulted in 326,065 crime records. The dates of the weeks that were used over the 10-year period are shown in Table 1. The dates are presented in four groups, which show before and after the Spring clock change and before and after the Autumn clock change.

Ambient light level was defined according to solar altitude. Daylight is characterized by a solar altitude of greater than 0°, i.e., the sun is above the horizon [38]. When the solar altitude is <0° daylight persists for a short period of time due to the reflection and scattering of sunlight towards the horizon of a terrestrial observer [38]. In this period, known as twilight, it is not fully daylit nor dark but a gradual transition between the two as solar altitude decreases. There are three defined stages of twilight; civil twilight, nautical twilight and astronomical twilight. In civil twilight, where solar altitude is between 0° and −6°, in clear weather there is sufficient daylight illuminance to enable outdoor civil activity to continue unhindered without resorting to the use of electric road lighting [38]. In nautical twilight (−6° to −12°) and astronomical twilight (−12° to −18°), detailed outdoor activities are restricted without artificial light. Thus, for the current purpose darkness is that period starting at the end of civil twilight after sunset (−6°) and ending at the beginning of civil twilight before dawn, and this includes nautical and astronomical twilight.

Solar altitude at the time of each crime was calculated using the National Oceanic and Atmospheric Administration (NOAA) method [39]. This method requires the date, time and the location (longitude and latitude) of a crime, all of which are provided in the CODE data set. This method therefore produced a precise solar altitude for the time and location of each specific crime. The solar altitude was also calculated for the exact same time for the paired week (i.e., if the crime took place on Monday the week before the clock change, then solar altitude was calculated also for 7 days after, Monday the week after the clock change, at the exact same time).

Table 1. The weeks before and after the Spring and Autumn clock change for the years 2010 to 2019 for Austin, Chicago and Louisville.

Spring Before		Spring After		Autumn Before		Autumn After	
Start	**End**	**Start**	**End**	**Start**	**End**	**Start**	**End**
7 March 2010	13 March 2010	14 March 2010	20 March 2010	31 October 2010	6 November 2010	7 November 2010	13 November 2010
6 March 2011	12 March 2011	13 March 2011	19 March 2011	30 October 2011	5 November 2011	6 November 2011	12 November 2011
4 March2012	10 March 2012	11 March2012	17 March 2012	28 October 2012	3 November 2012	4 November 2012	10 November 2012
3 March 2013	9 March 2013	10 March 2013	16 March 2013	27 October 2013	2 November 2013	3 November 2013	9 Novembetr 2013
2 March2014	8 March 2014	9 March 2014	15 March 2014	26 October 2014	1 November 2014	2 November 2014	8 November 2014
1 March 2015	7 March 2015	8 March 2015	14 March 2015	25 October 2015	31 October 2015	1 November 2015	7 November 2015
6 March 2016	12 March 2016	13 March 2016	19 March 2016	30 October 2016	5 November 2016	6 November 2016	12 November 2016
5 March 2017	11 March 2017	12 March 2017	18 March 2017	29 octobre 2017	4 November 2017	5 November 2017	11 November 2017
4 March 2018	10 March 2018	11 March 2018	17 March 2018	28 October 2018	3 November 2018	4 November 2018	10 November 2018
3 March 2019	9 March 2019	10 March 2019	16 March 2019	27 october 2019	2 November 2019	3 November 2019	9 November 2019

These values allowed for the dataset to be filtered to find crimes that occurred when the solar altitude was less than $-6°$ (i.e., after dark) and that if that crime had taken place the exact same time in the other paired week, the solar altitude would have been greater the $0°$ (i.e., in daylight). Similarly, crimes that happened when the sun's altitude was greater than $0°$ and that if that crime 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 summarized in the first five columns of Table 2.

Table 2. A summary of the study periods that were searched for crimes that met the inclusion criteria, along with the number of case and control crimes that occurred in each study period for the years 2010 to 2019.

Season	Time of Day	Period	Light Condition of Week	Light Condition of Paired Week	Number of Crimes	
					Case	**Control**
Spring	Morning	Before	Day	Dark	433	1355
		After	Dark	Day	367	1364
	Evening	Before	Dark	Day	2343	4927
		After	Day	Dark	2415	5520
Autumn	Morning	Before	Dark	Day	435	1401
		After	Day	Dark	400	1341
	Evening	Before	Day	Dark	2000	4746
		After	Dark	Day	2119	4657
			Total Dark		5264	12,349
			Total Day		5248	12,962
			Overall Total		10,512	25,311

For each of the time periods presented in Table 2, the number of crimes that met the inclusion criteria were determined. These are known as the case crimes, and these counts are also shown in Table 2, along with the total crimes that occurred in darkness and daylight.

It is possible that the change in the number of case crimes that happened during the weeks before and after the clock change occurred due to other factors not associated with ambient light level, for example seasonal influences such as the weather [40]. This was accounted for by counting crimes occurring in control periods either side of dusk and dawn, where the control period remained either daylight or dark before and after the clock change.

Durations of the case and control periods were matched. To do this the time windows for the case crimes were calculated separately for each study period (as seen in Table 2), for each year and for each city. These time windows are summarized in Table S1 for Austin, Table S2 for Chicago and Table S3 for Louisville.

This analysis used two control periods, one being in daylight before and after the clock change and the other being in darkness before and after the clock change. The time of the control periods were established by either adding or subtracting two hours to the original case time window. An interval of 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 06:48–07:15, then the dark control window was two hours before (04:48–05:15 a.m.), and the daylight control window was two hours after (08:48–09:15 a.m.). Therefore, any crimes that occurred in the dark control windows would have happened when the sun altitude was $\leq -6°$, and crimes that occurred in the daylight control windows would have happened when the sun altitude was $\geq 0°$. Crime counts were established for each of the control periods separately (Table 2).

The levels of crime type are based on the categories provided in CODE. To meet requirements of the Chi-Square test [41] some levels of crime type were removed when there were too few instances (fewer than 5 crimes in a particular cell) to perform a meaningful analysis. These omitted levels were bad cheques, bribery, embezzlement, extortion/blackmail, stolen property, human trafficking, kidnap/abduction, gambling, peeping tom and pornography. The category "all other offences" was also omitted as there was no explanation as to what crimes were included. All factors and levels, that were included and excluded can be seen in Table S4.

Following Johansson et al. [29], an Odds Ratio (OR) and associated 95% confidence interval (CI) were determined using Equations (1) and (2) to compare the case crime counts during darkness and daylight with the control crime counts. This OR gives a measure of the change in risk of a crime associated with darkness compared with daylight conditions.

$$\text{OR} = (\text{CaseDark}/\text{CaseDay})/(\text{ControlDark}/\text{ControlDay}) \tag{1}$$

$$\text{CI} = \exp(\ln(\text{OR}) \pm 1.96\sqrt{(((1/\text{CaseDark})/(1/\text{CaseDay}))/((1/\text{ControlDark})/(1/\text{ControlDay})))} \tag{2}$$

where:

CaseDark: the count of crimes that occurred when the solar altitude was $\leq 6°$, and the paired week was $\geq 0°$.
CaseDay: the count of crimes that occurred when the solar altitude was $\geq 0°$, and the paired week was $\leq 6°$.
ControlDark: the count of crimes in the Control periods on days when the Case crimes would be in darkness.
ControlDay: the count of crimes in the Control periods on days when the Case crimes would be in daylight.

First, ORs and 95% CIs were calculated to show the change in frequency at dark compared to daylight overall crime rates. This was calculated for all crimes, and separately for evening and morning crimes. 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 ($p < 0.05$) and a OR that is larger than 1.0 indicates a greater frequency of crime associated with dark conditions than with daylight conditions. ORs were also calculated for the overall crime rates in each city separately, for the different categories of crime, and for outdoor (street crime open space crime) and non-outdoor crime locations.

3. Results

Table 3 shows the ORs, 95% CIs and associated *p*-values for overall crime rates. As can be seen there is a significantly greater overall frequency of crime after dark compared with daylight. These overall data were also split according to time of day (evening or morning). Numbers of crimes are greater in the evening than in the morning, which is the expected trend for robberies at least. Significant effects of ambient light level were found for evening crimes but were not suggested to be significant for morning crimes. However, in all cases, the ORs do not reach the threshold (OR = 1.22) for even a small effect size [42,43] which suggests negligible practical relevance.

Table 3. ORs and 95% CIs associated with the change in crime frequency at dark compared to daylight. The associated *p*-values indicate whether the OR is significantly different to 1.0 (significant differences noted in bold font).

Comparison	Numbers of Crimes			Analysis		
	Time Window	Dark	Day	OR	95% CI	*p* Value
Overall Crime	Case	5264	5248	1.05	1.01–1.10	**$p = 0.03$**
	Control	12,349	12,962			
Evening Only Crime *	Case	4462	4415	1.08	1.03–1.14	**$p = 0.002$**
	Control	9584	10,266			
Morning Only Crime *	Case	802	833	0.94	0.84–1.05	$p = 0.26$
	Control	2765	2696			

* Morning was any crime to occur in case and control periods between 04:04–09:23 a.m. and evening was any crime that occurred in the case and control periods between 15:01–21:37.

Table 4 shows the ORs, 95% CIs and associated *p*-values for overall crime rates as determined separately for the three cities. There is a significantly greater overall frequency of crime after dark compared with daylight in Chicago, although the OR does not reach the threshold for a small effect size, and the effect is not suggested to be significant in Austin or Louisville.

Table 4. ORs and 95% CIs associated with the change in crime frequency at dark compared to daylight for the three separate cities. The associated *p*-values indicate whether the OR is significantly different to 1.0 (significant differences noted in bold font).

City	Number of Crimes			Analysis		
	Time Window	Dark	Day	OR	95% CI	*p* Value
Austin	Case	1482	1522	1.02	0.94–1.11	$p = 0.67$
	Control	3246	3396			
Chicago	Case	3286	3198	1.08	1.02–1.14	**$p = 0.01$**
	Control	8156	8536			
Louisville	Case	496	528	1.02	0.88–1.19	$p = 0.78$
	Control	947	1030			

Table 5 shows the ORs, 95% CIs and associated *p*-values for the two outdoor locations, streets and open spaces, and for all other locations combined. These data do not suggest a significant effect of ambient light level in any case. (Note, analysis of the remaining individual crime locations also did not suggest significant effects).

Table 5. ORs and 95% CIs associated with the change in crime frequency at dark compared to daylight for street crimes and non-street crimes. The associated *p*-values indicate whether the OR is significantly different to 1.0.

Location	Numbers of Crimes			Analysis		
	Time Window	Dark	Day	OR	95% CI	*p* Value
Street Crimes	Case	1658	1643	1.08	0.99–1.17	$p = 0.07$
	Control	3992	4259			
Open space (green space)	Case	424	434	1.03	0.87–1.21	$p = 0.76$
	Control	880	924			
All crime locations excluding street and open space	Case	3174	3160	1.04	0.98–1.10	$p = 0.18$
	Control	7465	7740			

Table 6 shows the ORs, 95% CIs and associated *p*-values for the different levels of crime type. For the 21 types of crime included, the Holm-Bonferroni sequential correction [44] for multiple statistical tests was applied to control the Type 1 error rate. A significant effect of change in ambient light level was found for only one type of crime, robbery (OR = 1.58, 95%CI = 1.23–2.04, $p < 0.05$), for which the OR suggests a small (1.22) to medium (1.86) effect size [42,43]. As expected, no significant effects were suggested for any other types of crime.

Table 6. ORs and 95% CIs associated with the change in risk at dark compared to daylight according to type of crime. These data are for three US cities-Austin, Chicago and Louisville. The associated p-values indicate whether the OR is significantly different to 1.0.

Crime Type	Number of Events				Analysis		
	Dark Case	Day Case	Dark Control	Day Control	OR	95% CI	p Value
Arson	7	5	15	18	1.68	0.44–6.40	$p = 0.45$
Assault	1142	1188	2896	3098	1.03	0.93–1.13	$p = 0.57$
Burglary/breaking & entering	265	315	619	675	0.92	0.75–1.12	$p = 0.39$
Counterfeiting/forgery	32	30	69	74	1.14	0.63–2.08	$p = 0.66$
Curfew/loitering	14	6	8	7	2.04	0.51–8.23	$p = 0.31$
Destruction of property	485	442	1124	1226	1.20	1.03–1.39	$p = 0.02$
Disorderly conduct	91	114	194	196	0.81	0.57–1.13	$p = 0.21$
Driving under the influence	39	32	100	83	1.01	0.58–1.75	$p = 0.97$
Drug offences	529	559	1442	1448	0.95	0.83–1.09	$p = 0.47$
Drunkenness	40	41	83	101	1.19	0.70–2.00	$p = 0.52$
Family offences (non-violent)	19	16	32	21	0.78	0.33–1.85	$p = 0.57$
Fraud	177	186	462	467	0.96	0.76–1.23	$p = 0.75$
Homicide	11	8	26	21	1.11	0.38–3.26	$p = 0.85$
Larceny/theft	1277	1294	2745	2947	1.06	0.97–1.16	$p = 0.22$
Liquor law violation	11	16	14	18	0.88	0.31–2.50	$p = 0.82$
Motor vehicle theft	195	159	392	354	1.11	0.86–1.43	$p = 0.43$
Prostitution	14	25	59	71	0.67	0.32–1.41	$p = 0.29$
Robbery	211	136	412	420	1.58	1.23–2.04	$p < 0.001$ *
Sex offences	20	19	50	48	1.01	0.48–2.12	$p = 0.98$
Trespass of real property	157	137	379	321	0.97	0.74–1.28	$p = 0.83$
Weapon law offences	74	71	187	189	1.05	0.72–1.55	$p = 0.79$

* Significant $p < 0.05$ with Holm-Bonferroni Sequential Correction.

4. Discussion

These analyses suggest a statistically significant increase in overall crime after dark (OR = 1.05) although this does not reach the suggested threshold (OR = 1.22) [43] for a small effect size and is thus not suggested to be of practical relevance.

A statistically significant effect of ambient light level was found for one type of crime, robbery, with the OR (1.58) suggesting an increase in robbery after dark compared with daylight, confirming previous work concluding that robbery is influenced by ambient light level [11,22]. As noted above, the assumed anonymity from darkness promotes moral transgressions [23]; darkness also impairs vision and hence reduces the ability to detect an approaching robber and subsequently identify them. Xu et al. [10] also note previous work concluding that that higher visibility was significantly correlated ($p < 0.01$) with fewer robberies of retail stores in the US, giving the proposition that robbers choose their targets based on the likelihood of the robbery being witnessed from outside the store. For other types of crime, these data do not suggest a significant effect of changes in ambient light level.

Similar to robbery, other types of crime such as assault and sex offences also involve interpersonal contact yet for these the data do not suggest a significant effect of ambient light level. This may be because these crimes occur in indoor as well as outdoor locations, and change in ambient light level is not expected to affect crimes occurring indoors. Similarly, analysis of crimes by location (Table 5) does not suggest a significant effect of ambient light level on street crimes (nor other locations), which may be because robberies are mixed with other types of crime for which there is no effect of ambient light level.

While Table 6 does not reveal a significant effect of ambient light level for crime types other than robbery, the ORs indicates an effect size of at least a small practical relevance for five other types of crime. For arson (OR = 1.68) and curfew/loitering (OR = 2.04) the ORs exceed the thresholds for small (OR = 1.22) and medium (OR = 1.86) effect sizes, respectively [43], indicating an increase in these types of crime after dark. Darkness makes it easier to initiate an act such as arson without being seen. For curfew/loitering offenses, the anonymity of darkness means people are more willing to loiter, which could represent a violation of a court order, regulation or law prohibiting inhabitation of specified areas. For three types of crime (Disorderly conduct, Family offences (non-violent) and Prostitution) the ORs are between the thresholds for small (0.82) and medium (0.54) effect sizes [43], indicating a decrease in these types of crime after dark. Counts of disorderly conduct, behaviour that tends to disturb the public or decorum, scandalize the community, or shock the public sense of morality [45], may decline after dark because police are less well able to detect these offenses in darkness. For prostitution, while the police or local authority might suggest improved road lighting to reduce activity [46,47], informal observation has suggested the opposite outcome: prostitutes were observed to move to a university campus following the installation of improved lighting, designed for student safety, because it offered a more-secure working environment [48]. This benefit is supported by research of lighting for pedestrians where the presence road lighting [49], and brighter road lighting [50] enhance the feeling of safety.

One reason why the OR is not suggested to be significantly different from 1.0 for these five cases of at least small effect size is that the small sample sizes lead to wider confidence intervals [51]. To investigate this, the sample sizes (numbers of crimes in the case and control periods, for daylight and dark conditions) were inflated to estimate those for the whole of the USA. Consider arson in the case-dark period: for Austin, Chicago and Louisville these 7 cases (Table 6) represent 0.13% of the total number of arson cases in those regions. Crime data for the whole of the USA were taken from the FBI Uniform Crime Reporting (UCR) Programme website for the years 2010 to 2019 to match the original dataset. The total number of arson cases is 73,295, of which 0.13% is 95. This process was repeated for all crime types (Table 7). The scaling factors are shown in Table S5. This weighting process means that the OR is unaffected but the confidence interval becomes smaller than that found with the three-city data set. Table 7 shows those crime types for which a significant effect ($p < 0.05$) is now suggested, with the Holm-Bonferroni correction applied.

Consider the six crime types for which the effect of ambient light level is suggested to be of at least a small effect size. For disorderly conduct, family offences (non-violent) and prostitution there is a significant ($p < 0.05$) decrease in crime after dark: for curfew/loitering and robbery there is a significant increase after dark. For arson, the estimated significance ($p = 0.005$) is only marginally above the Holm-Bonferroni corrected threshold ($p = 0.0045$) for significance.

The clock change approach to investigating the effect of light on crime does not involve an intervention. Therefore, where a significant effect is revealed, this must be an effect directly attributable to light (i.e., a change in vision) rather than an indirect effect (i.e., a response to there being an intervention) and thus supports the surveillance theory for the effect of lighting on crime. When data for three cities were analysed a significant and practically relevant effect of change in ambient light level was found for robbery. When these data samples were scaled to represent the USA as a whole, significant and practically relevant effect of change in ambient light level were also found for five additional crime types. An investigation using ambient light level gives an indication of the potential for outdoor lighting. Hence, these data suggest outdoor lighting would mitigate the increases in robbery, arson, and curfew/loitering offenses; at the same time, however, it might also counter the reductions in disorderly conduct, family offences (non-violent) and prostitution that occur after dark.

Table 7. ORs and 95% CIs associated with the change in risk at dark compared to daylight according to type of crime. These are estimated case and control data for the whole of the USA. The associated *p*-values indicate whether the OR is significantly different to 1.0.

Crime Type	Dark Case	Day Case	Dark Control	Day Control	OR	95% CI	*p* Value
Arson	95	68	203	243	1.68	1.16–2.40	$p = 0.005$
Assault	13,265	13,800	33,640	35,986	1.03	1.00–1.06	$p = 0.05$
Burglary/breaking & entering	1722	2047	4023	4387	0.92	0.85–0.99	$p = 0.03$
Counterfeiting/forgery	449	421	969	1039	1.14	0.98–1.34	$p = 0.10$
Curfew/loitering	1146	491	655	573	2.04	1.75–2.38	$p = 0.001$ *
Destruction of property	1721	1568	3988	4350	1.20	1.10–1.30	$p = 0.001$ *
Disorderly conduct	5437	6811	11,590	11,710	0.81	0.77–0.84	$p = 0.001$ *
Driving under the influence	6155	5050	15,782	13,099	1.01	0.97–1.06	$p = 0.61$
Drug offences	14,754	15,591	40,219	40,386	0.95	0.93–0.98	$p = 0.001$ *
Drunkenness	4210	4315	8736	10,630	1.19	1.13–1.25	$p = 0.001$ *
Family offences (non-violent)	1276	1074	2149	1410	0.78	0.70–0.87	$p = 0.001$ *
Fraud	208	218	542	548	0.96	0.77–1.21	$p = 0.75$
Homicide	174	127	412	333	1.11	0.85–1.45	$p = 0.46$
Larceny/theft	9582	9710	20,598	22,113	1.06	1.02–1.10	$p = 0.001$ *
Liquor law violation	2975	4328	3787	4869	0.88	0.83–0.94	$p = 0.001$ *
Motor vehicle theft	647	528	1301	1175	1.11	0.96–1.27	$p = 0.15$
Prostitution	222	397	936	1126	0.67	0.56–0.81	$p = 0.001$
Robbery	1122	723	2190	2233	1.58	1.42–1.77	$p = 0.001$ *
Sex offences	428	406	1069	1026	1.01	0.86–1.19	$p = 0.89$
Trespass of real property	320	279	772	654	0.97	0.80–1.18	$p = 0.77$
Weapon law offences	1415	1357	3575	3614	1.05	0.97–1.15	$p = 0.24$

* Significant $p < 0.05$ with Holm-Bonferroni Sequential Correction.

Consider three limitations of this analysis. First, crime data from only three US cities were used, extracted from the Crime Open Database which includes data for only 16 cities. To expand this to represent the whole of the USA, it was assumed that the proportions of each crime type falling within each of the case and control periods were similar to those established for the three cities, as shown in Table S5. Second, the categorization of a crime as occurring in either daylight or darkness was made through determination of solar altitude for each crime event according to the date, time and location. There may be errors in the recording of these data as has been found in records of road traffic crashes. Errors have been found in crash location [52–55] and crash time [56]. Third, the current investigation chose to collect data for one week either side of the clock change, similar to previous investigation of RTCs [32] but shorter than the two [57] and five [58] weeks used by others. There does not yet appear to consensus about the number of weeks that should be considered. The smaller period produces a smaller sample of events but with greater focus on the impact of change in ambient light rather than other changes. Further work is required to determine how the choice of sample duration effects analysis outcomes.

Having established the potential for road lighting to reduce crime through increased visibility, then next step is to establish the relationship between crime and characteristics of lighting. This can be done by establishing ORs separately for locations of different lighting characteristics, as has been done to investigate cyclist flows [9]. A key parameter of road lighting is the amount of light, and in that study light level was estimated using aerial photographs. Other studies have used the density of road lights [10] but that is an unreliable estimate for the amount of light as it ignores variations in lamp type, lamp wattage, lantern optics and lamp post height. It would also be useful to further investigate the cost effectiveness of improved street lighting [59] as a counter measure to crime given that improved lighting may not be beneficial for all types of crime.

5. Conclusions

Sustainable road lighting requires careful optimization of the costs and benefits. One of the assumed benefits of road lighting in subsidiary roads is a reduction in crime. The potential benefit of improved visibility was investigated by considering the effect of changes in ambient light level on crimes in three US cities, using an odds ratio to isolate the effect of ambient light level (daylight vs. dark) from other environmental factors. For these three cities a statistically significant result was found for only one type of crime, robbery, with an increase in robbery after dark. However, for other types of crime the odds ratio suggested an effect size of practical relevance for five additional types of crime, and statistically significant effects were suggested when the data were scaled up to reflect crime counts for the whole of the US.

For three types of crime (robbery, arson, and curfew/loitering offences), improved road lighting has the potential to offset the increase in crime associated with darkness. However, darkness led to a reduction in three different types of crime (disorderly conduct, family offences (non-violent) and prostitution) and for these, improved road lighting might counter that reduction.

While guidance [2,3] suggests that improved road lighting discourages crime, this analysis suggests that only certain types of crime are discouraged by the enhanced visibility (or reduced anonymity); other types of crime may be enhanced. Future research investigating the effectiveness of improved street lighting should, therefore, consider that this may not be beneficial for all types of crime. The current findings require validation using additional data to expand the sample and compare findings across locations of different environmental and socio-cultural characteristics. Further research is also needed to better understand the contributions of visibility and community pride to crime reduction.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/en14144099/s1, Table S1: The case and control time windows for Austin, Table S2: The case and control windows for Chicago, Table S3: The case and control windows for Louisville, Table S4: All crime types in CODE and reasons for omission, Table S5: Scaling factors for each crime type.

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