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The Society of
Light and Lighting

Using segmented regression to estimate the optimal illuminance for pedestrian reassurance

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CIE 115:2010 gives guidance for the design of road lighting that feeds into the design standards of many nations. There is, however, an emerging awareness that the guidance in CIE 115:2010 needs amendment, and this is being targeted through rapid and long-term revisions. One aim of the rapid revision is to provide an empirical basis for the guidance, with that to be founded in what is already known rather than waiting for further research to be conducted. For P-class lighting, applied to situations where pedestrians are the target user, it has been suggested that pedestrian reassurance (the feeling of safety) is a suitable basis for establishing optimal lighting conditions. This article analyses the relationship between measures of pedestrian reassurance (after-dark evaluations and the difference between daylight and after-dark evaluations) and the conventional measures of lighting in the P class (mean, minimum and uniformity of horizontal illuminance) using the results from previous field studies investigating this. For these data, the day-dark difference provided a better association with illuminance than did after-dark ratings. For the day-dark difference, the association with mean illuminance was better than that with minimum illuminance or uniformity. Segmented regression suggested an optimum mean illuminance of 8.76 lx. To fit within the existing P classes, this could be rounded down to class P3 (mean illuminance = 7.5 lx).

1. Introduction

CIE 115:2010 *Lighting of Roads for Motor and Pedestrian Traffic*¹ reports ‘current knowledge and experience’ about road lighting, including two series of lighting classes for motorists (M class) and pedestrians (P class). For those classes, it recommends lighting conditions, and it also describes a series of factors that can be used for choosing an appropriate class. CIE 115:2010

is an important document because those recommendations are the basis of national guidance for road lighting. For example, it is the basis of class selection in EN 13201-1:2014 and lighting conditions in EN 13201-2:2015,^{2,3} which in turn are the basis of lighting design criteria in BS5489-1:2020.⁴

There are, however, some limitations to the guidance given in CIE 115:2010.^{5,6} One key issue is that the document does not reveal the evidence used to determine the recommended lighting conditions nor the reasons for the factors and weightings used to establish a certain lighting class. This need is recognised by CIE, and hence a revision of CIE115:2010 is a priority focus of activity in

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Division 4 of the CIE. In the first place, this is intended to be a rapid revision, using evidence already available rather than waiting for further research to be funded and completed.

The current article aims to establish an empirical basis for optimal lighting conditions in the P class and does so through an analysis of the results of previous studies investigating pedestrian reassurance. Pedestrian reassurance describes *'the confidence a pedestrian might gain from road lighting (and other factors) to walk along a footpath or road, in particular if walking alone after dark'*,⁷ and is intended to encompass the terms used in past studies such as perceived safety,⁸ perceived danger^{9,10} and fear of crime.¹¹ Reassurance is a consideration of social importance because people are more likely to walk when they feel safe,^{12,13} particularly so for women.¹⁴ This is recognised in design guidance, with one document⁴ stating that a purpose of road lighting in subsidiary roads is to *'allow pedestrians to ... feel more secure [and] ... helping to reduce fear of crime'*, while a second document¹ states that good lighting in a residential area *'imparts a greater sense of security'*.

Reassurance is a useful consideration for establishing an optimal illuminance for P-class lighting. It requires a higher illuminance than that needed for the detection of trip hazards,^{7,15} itself an important consideration because falls on public footpaths are a significant problem in terms of the number of cases, the severity of the resulting injury and the national cost.¹⁶ Another visual need of pedestrians is to evaluate the intentions of other people, but there is insufficient evidence as to what lighting conditions are desirable. For example, previous studies have tended to ask test participants to identify the identity of celebrities, typically of light skin tone, with a full-face view, and with an unlimited observation period, and these conditions do not represent experience.^{17–20} Furthermore, sufficient light to appraise another

person may be a source of glare on that other person, and this balance remains unresolved.

Road lighting is expected to support reassurance because it aids the visual evaluations of prospect, refuge and escape,²¹ and indeed road lighting is associated with locations considered safe to walk after dark.^{22,23} That suggests road lighting should be installed where the need to support reassurance is pertinent, but it does not say how much light should be provided.

To estimate how a change in illuminance affects reassurance, previous field studies have tended to evaluate reassurance only after dark, with a small sample of locations of different illuminance, and have tended to conclude that the higher the illuminance received, the higher rating of reassurance. Such results are described in CIE 236:2019 as trivial because *'no matter what light levels are used, the higher will be rated as safer, leading to a recommendation for that higher light level'*.⁷ This stimulus range effect leads towards ever higher illuminances rather than establishing an optimal illuminance.²⁴

There is evidence that an optimal light level can be established by either of two changes to the standard approach: (1) by using a much larger sample of locations,²⁵ or (2) by conducting reassurance evaluations also in daylight and using the day-dark difference as the measure of lighting effectiveness – good lighting is that which minimises the difference between daylight and after-dark evaluations of the same location.²⁶

The aim of this article is to make an estimate of the optimal illuminance for pedestrian reassurance using results from the day-dark approach to measuring the effectiveness of lighting. By including all known studies using this method, it expands the sample size. The current article extends interim publication of the work²⁷ through the inclusion of additional studies, the correction of errors (incorrect conversion of the 5-point response scale used by Wei *et al.*²⁸ to a

Table 1 Studies of pedestrian reassurance were omitted from the current analysis

Reason for exclusion	Excluded studies
Evaluations were not field studies, i.e., used instead photographs, VR environments or scale models	Boomsma and Stegg, ³⁰ Bullough <i>et al.</i> , ³¹ Loewen <i>et al.</i> , ³² Wu and Kim ³³
The evaluations were independent samples	Mattoni <i>et al.</i> , ³⁴ Peña-García <i>et al.</i> ³⁵
Five or fewer locations were evaluated	Akashi <i>et al.</i> , ³⁶ Nair <i>et al.</i> , ³⁷ Painter, ³⁸ Rea <i>et al.</i> , ³⁹ Vrij and Winkel ⁴⁰
Illuminance was neither measured nor reported	Atkins <i>et al.</i> , ¹¹ Blobaum and Hunecke, ⁹ Nair <i>et al.</i> , ⁴¹ Herbert and Davidson ⁴²
Reported spot illuminance rather than measurement following EN 13201-3:2015	Portnov <i>et al.</i> , ²⁵ Svechkina <i>et al.</i> ⁴³
Reported the change in ratings under different lighting conditions, but not the absolute ratings of each condition	Knight ⁸

common 6-point scale, and incorrect reporting of samples in previous studies), analysis of optimal illuminance using after-dark evaluations alone, and the use of an independent statistician to apply segmented regression.

2. Method

2.1 Included data

The primary focus of analysis was studies of pedestrian reassurance under different lighting conditions using the day-dark method. Studies using only after-dark evaluations were also included to test the assumption that the day-dark difference provides better characterisation of reassurance. The inclusion criteria were:

- A field study, i.e., *in situ* evaluations of locations.
- A repeated measures design was used, in which each test participant evaluated all locations (in both daylight and after-dark, where the day-dark difference was analysed).
- Five or more locations were evaluated.

- Illuminance characteristics were derived from spot illuminances measured across an array of nodes, such as the approach defined in EN 13201-3:2015,²⁹ rather than a single spot measurement at a location.

Table 1 lists the studies that did not meet these criteria and were hence omitted from the analysis.

The minimum threshold of five locations was set as an attempt to offset the expected bias from the stimulus range effect. While this was an arbitrary threshold, exclusion of the five studies not meeting this threshold (see Table 1) removed 11 cases from the after-dark analysis but none from the day-dark analysis. The five omitted studies reported evaluations of only two or three locations (or the same location with two or three lighting conditions).

Table 2 shows those studies that met the inclusion criteria and were therefore included in the analysis. Five studies^{28,44–47} examined pedestrian reassurance in urban roads, one study examined reassurance in parking lots,²⁶ and one study was located in an arboretum with lighting from low level bollards rather than lamp posts.⁴⁸

Table 2 Studies of pedestrian reassurance included in the current analysis show the locations of illuminance and evaluation data in the original publications. All studies used the day-dark approach except Himschoot *et al.*⁴⁸ which sought only after-dark evaluations

Study	Location	No. of locations	Lamp type	No. of test participants	Reassurance evaluation (a)	Response scale range	Location of data used in the current analysis		
							Illuminance	After-dark ratings	Day-dark differences
Fotios <i>et al.</i> ⁴⁴ (b)	Sheffield, UK	8	Mixed	24	Composite	1–6	Table 1	Supplemental data	Table 5
Gorjimahlabani ⁴⁵	Sheffield, UK	12	LED	122	Composite	1–6	Table 5.2	Table 6.16	Table 6.16
Liachenko	Sheffield, UK	16	Mixed	34	Composite	1–6	Table 21	Appendix H	Table 25
Monteiro ⁴⁶ (c)									
Unwin ⁴⁷ (d)	Sheffield, UK	9	Mixed	46	Single	1–6	Table 6.1	Figure 6.10	Table 6.12
Wei <i>et al.</i> ²⁸	Ljubljana, Slovenia	11	Mixed	35	Composite	1–5	Table 1	Table 4	Table 7
Boyce <i>et al.</i> ²⁶ (e)	Albany, NY	24	Not reported	18	Single	1–7	Figure 7	Not reported	Figure 7
Himschoot <i>et al.</i> ⁴⁸	An arboretum in the United States (f)	8	LED	156	Single	5 pt (g)	Table 2	Table 2	Not done

(a) The evaluations focused on perceived safety at that location: *composite* means factor analysis was used to derive a single measure from multiple ratings scales; *single* means only one relevant scale was used.

(b) This is Field Study 1 in Liachenko Monteiro⁴⁶

(c) This is the work labelled as Field study 2.

(d) This is the work labelled as 'Winter study'.

(e) This is the work labelled as Field study 3.

(f) This location was described as 'a large U.S. university-managed arboretum within a multi-mile wooded trail system'.

(g) See comment on this scale in section 2.2.2.

All studies were included where possible in both analyses (the day-dark difference and the after-dark ratings), with the reassurance data being compared with mean, minimum and uniformity of illuminance. Himschoot *et al.*⁴⁸ recorded evaluations only after dark, so it is omitted from the day-dark difference analysis. Boyce *et al.*²⁶ recorded evaluations in both daylight and after dark, thus to determine the day-dark difference, but did not report the after-dark evaluations, and were therefore omitted from the after-dark analysis.

Three studies^{44–46} reported a composite score of reassurance determined using factor analysis of day-dark differences determined from the responses to multiple questions, including *How safe do you think this street is?*, *How anxious do you feel when walking down this street?* and *I would rather avoid this street if I could*. Similarly, Wei *et al.*²⁸ reported the composite score determined from three questions addressing safety, risk and comfort. However, only one study⁴⁵ followed that same process for analysis of the after-dark ratings. For the other three studies, the current analysis used:

- Fotios *et al.*: The mean of responses to the three questions about safety, anxiousness and avoidance.⁴⁴
- Liachenko Monteiro: The mean of responses to the two questions about safety and anxiousness. Responses to the avoidance question were omitted since it is not clear whether or not the scale direction had been reversed in the reported data.⁴⁶
- Wei *et al.*: Responses to only the question about safety. Responses to the question about risk were omitted since it is not clear whether or not the scale direction had been reversed in the reported data.²⁸

Boyce *et al.*²⁶ asked multiple questions but reported only the responses to the question asking how risky it would be to walk alone at night.

Finally, two studies asked only one question, that being about the feeling of safety.^{47,48}

2.2 Data manipulation

Consideration was given to the inclusion of individual locations in the original studies, the rating scales used to record evaluations, and the reported lighting conditions.

2.2.1 Location omission

Data for all of the locations reported in the previous studies were retained except for three. The two locations in Fotios *et al.*⁴⁴ identified as being different types of environments were omitted to follow the collection labelled as ‘N=8’ in that study. Location R8 in Wei *et al.*²⁸ was omitted as it was unlit.

2.2.2 Response scale conversion

The analysis reported here assumes that the reassurance questionnaires used a 6-point rating scale where 1 represents low reassurance and 6 represents high reassurance. Such a scale was originally used in four studies.^{44–47} For some questions, the direction of the response scale was reversed (i.e. 1 represented high reassurance and 6 represented low reassurance), this being a step to check for attentive responding. Where the original study reported the reversed data, this was used in the current analysis; where it is clear that the ratings have not been reversed to account for scale direction, this was done for the current analysis; where there is uncertainty, these data were omitted from the analysis.

Wei *et al.*²⁸ used a 5-point rating scale ranging from 1 to 5. These responses were converted to a 1–6 response scale using Equation (1), where R_{1-5} is the original rating using a 1–5 response scale and R_{1-6} is the rating when converted to a 1–6 response scale.

$$R_{1-6} = ((R_{1-5} - 1)5/4) + 1 \quad (1)$$

Table 3 Inclusion of studies within the analysis of the prediction of reassurance by the given lighting measure, according to the availability of data

Study	After dark			Day-dark difference		
	Mean	Minimum	Uniformity	Mean	Minimum	Uniformity
Fotios <i>et al.</i> ⁴⁴	✓	✓	✓	✓	✓	✓
Gorjimahlabani ⁴⁵	✓	✓	✓	✓	✓	✓
Liachenko Monteiro ⁴⁶	✓	✓	✓	✓	✓	✓
Unwin ⁴⁷	✓	✓	✓	✓	✓	✓
Wei <i>et al.</i> ²⁸	✓	✓	✓	✓	✓	✓
Boyce <i>et al.</i> ²⁶				✓		
Himschoot <i>et al.</i> ⁴⁸	✓					

Day-dark differences determined from a 1 to 6 rating scale would range from 5 (a day rating of 6 and a dark rating of 1) to 0 (the same rating for daylight and after dark) or even to negative values (the daylight rating being lower than the dark rating). The day-dark differences reported by Wei *et al.* were therefore multiplied by 5/4 to convert them to a day-dark difference range of 0–5. Boyce *et al.*²⁶ used a 1–7 response range, meaning that their day-dark difference range of 0–6 required multiplication by 5/6 to convert it to that which would be gained from ratings using a 1–6 response scale.

The studies listed in Table 2 tended to assign each category in their response scale the integer 1, 2, ... 6 and reported the average value of these ratings. Himschoot *et al.*⁴⁸ instead reported the proportion of responses awarded to each of their five categories. For the current analysis, these categories were assumed to be represented by the integers 1 to 5, a mean rating was estimated using those proportions as a weighting for the assigned integer, and the resulting mean converted to that for a 1–6 response range using Equation (1).

2.2.3 Illuminance data

The current analysis investigated the association between reassurance (the day-dark difference and

the after-dark ratings) and the mean, minimum and uniformity of illuminance, these being the primary characteristics of design guidance for P class lighting.^{1,4} In three studies^{28,45,46} all three values were reported. In two studies^{44,47} the mean illuminance was reported but with only the minimum or uniformity: the third value was thus calculated from the other two values. Note that for the current analysis study, uniformity of illuminance was defined as the ratio of minimum illuminance to mean illuminance. In the final two studies^{26,48} only mean illuminance of each location was reported, so it was not possible to determine the minimum illuminances or uniformities. Note that Boyce *et al.* reported median illuminance rather than mean. The current analysis, therefore, used their median illuminance, following a study that suggested that mean and median illuminance are sufficiently similar.⁴⁹ Table 3 shows the studies included in each specific analysis.

2.3 Data analysis

Regression analysis was used to explore the relationship between the measures of lighting (mean, minimum and uniformity of illuminance) and evaluations of reassurance (after-dark ratings and the day-dark difference). A lighting measure providing a sufficient prediction of reassurance

Table 4 Results of regression analysis exploring lighting measures for predicting reassurance

Reassurance	Illuminance characteristic	Equation*	N	R^2	p value	Residuals	
Day-dark difference	Mean	Log	$R_{DD}=2.1073-0.655 \ln(E_{\text{mean}})$	80	0.42	<0.001	No trend
	Minimum	Log	$R_{DD}=0.6138-0.279 \ln(E_{\text{min}})$	56	0.44	<0.001	No trend
	Uniformity	Linear	$R_{DD}=0.801-0.9842 (U)$	56	0.16	0.02	No trend
After dark	Mean	Linear	$R_{AD}=3.718+0.0559 (E_{\text{mean}})$	64	0.10	0.009	No trend
	Minimum	Log	$R_{AD}=4.0204+0.3544 \ln(E_{\text{min}})$	56	0.30	<0.001	No trend
	Uniformity	Linear	$R_{AD}=3.6212+1.9142 (U)$	56	0.27	<0.001	No trend

*Reassurance evaluations are noted as R_{DD} for the day-dark difference and R_{AD} for the after-dark rating.

was one for which the best-fit line suggested a statistically significant relationship ($p < 0.05$) and for which the plot of residuals suggested a random distribution. The lighting measure(s) suggesting the better prediction of reassurance were those providing the higher coefficient of determination (R^2) – the higher the R^2 value, the greater the percentage of change in the reassurance ratings that is explained by the change in that specific lighting measure.

For the lighting measure(s) suggesting good prediction of reassurance, the optimal value of that measure was determined using segmented regression.^{25,50,51} Segmented regression separates the data into two (or more) segments, separated at a break point, with each segment characterised by a separate linear equation. The break point between the two segments defines the optimal value of that lighting measure and for the current analysis was defined through iterative choices of the break point such that: (i) the region above the break point is a flat line (a slope of 0), indicating that illuminances higher than the break point bring no further increase in reassurance; and (ii) the region below the break point displays a significant relationship between lighting measure and reassurance, with a lower value of (e.g.) mean illuminance suggesting a lower degree of reassurance.

Segmented regression was implemented using the *segmented* package in *R*. Segmented regression models were fitted to each dataset separately, applying either one or two break points (for two or three segments, respectively). The gradient of the final segment was constrained to zero (horizontal fitted line) where possible. Likelihood ratio tests (used for comparing the goodness of fit of two competing statistical models) were used to assess the improvement in fit for the segmented model versus a simple linear fit, and for two versus one break points.

3. Results

3.1 Regression analysis

The distributions considered are the reported mean reassurance rating (after-dark or day-dark difference) and the reported mean, minimum and uniformity of illuminance for each location. The regression considered linear and logarithmic best-fit lines, with a linear equation proposed unless the logarithmic equation produced a higher R^2 value. Table 4 shows the results of the regression analysis. To check the sensitivity of these relationships, the regressions were repeated with individual studies removed. The removal of any one study did not lead to a marked change in the relationships between the illuminance and

reassurance variables. Figures 1 and 2 show these relationships.

In all cases, the association between lighting and reassurance is suggested to be statistically significant ($p < 0.05$), and no non-random patterns were observed in the residual plots. For the day-dark difference, mean and minimum illuminance are better predictors than uniformity; for the after-dark ratings, minimum illuminance and uniformity are better predictors than mean illuminance. With these data, the weakest association found is that between after-dark ratings of reassurance and mean illuminance. There is a stronger association between illuminance and reassurance for the day-dark difference than for after-dark ratings. Overall, the data presented in Table 4 suggest that using mean or minimum illuminance to predict the day-dark difference is the best approach for predicting the benefit of lighting for pedestrian reassurance.

3.2 Segmented regression

Segmented regression revealed break points for the regression of the day-dark difference against either mean illuminance or minimum illuminance (Figure 3). These suggest optimal mean and minimum illuminances of 8.76 lx (95% confidence interval 6.20 lx to 11.32 lx) and 1.54 lx (0.88 lx to 2.20 lx) respectively. For the other four data sets, segmented regression was not able to reveal a break point leading to a significant improvement in fit.

4. Discussion

4.1 Main findings

To support the rapid revision of CIE 115:2010,¹ this article reports an analysis of the results from previous field studies about the relationship between lighting conditions and pedestrian reassurance in order to estimate the optimal

illuminance for pedestrian reassurance. Six combinations of three lighting criteria (mean, minimum and uniformity of illuminance) and two reassurance evaluations (after-dark and the day-dark difference) were examined. It was found that a change in mean or minimum illuminance exhibits a better association with the day-dark difference in reassurance than with after-dark ratings (Table 4). Segmented regression was able to identify optimal values (break points) in the regressions of day-dark difference against either mean or minimum illuminance but was not able to reveal such points in any of the other four combinations.

The rapid revision of CIE 115:2010 intends that the existing set of lighting classes is retained. The optimal criteria determined in the current analysis (mean illuminance = 8.76 lx, minimum illuminance = 1.54 lx) lie between classes P3 (mean = 7.5 lx, minimum = 1.5 lx) and P2 (mean = 10 lx, minimum = 2.0 lx). On the basis that the lower illuminance of P3 is still within the confidence interval of the estimated optimal values, and that lower illuminance contributes to a reduction in the unwanted impacts of lighting after dark, then for the locations included in the current analysis, it can be concluded that lighting class P3 would be the optimal choice.

Figure 3 shows that the horizontal segment in each graph lies at a day-dark difference of about 0.5, close to the day-dark difference of 0 obtained when the same degree of reassurance is reported in daylight and after dark. This indicates what we should expect from lighting after dark – it has the potential to raise reassurance towards that found in daylight but is unlikely to reach the same level. That does not necessarily mean a high level of reassurance at a location, because other factors, such as signs of incivility, may result in a low level of reassurance even in daylight; instead, it means this is the best that road lighting is able to do.

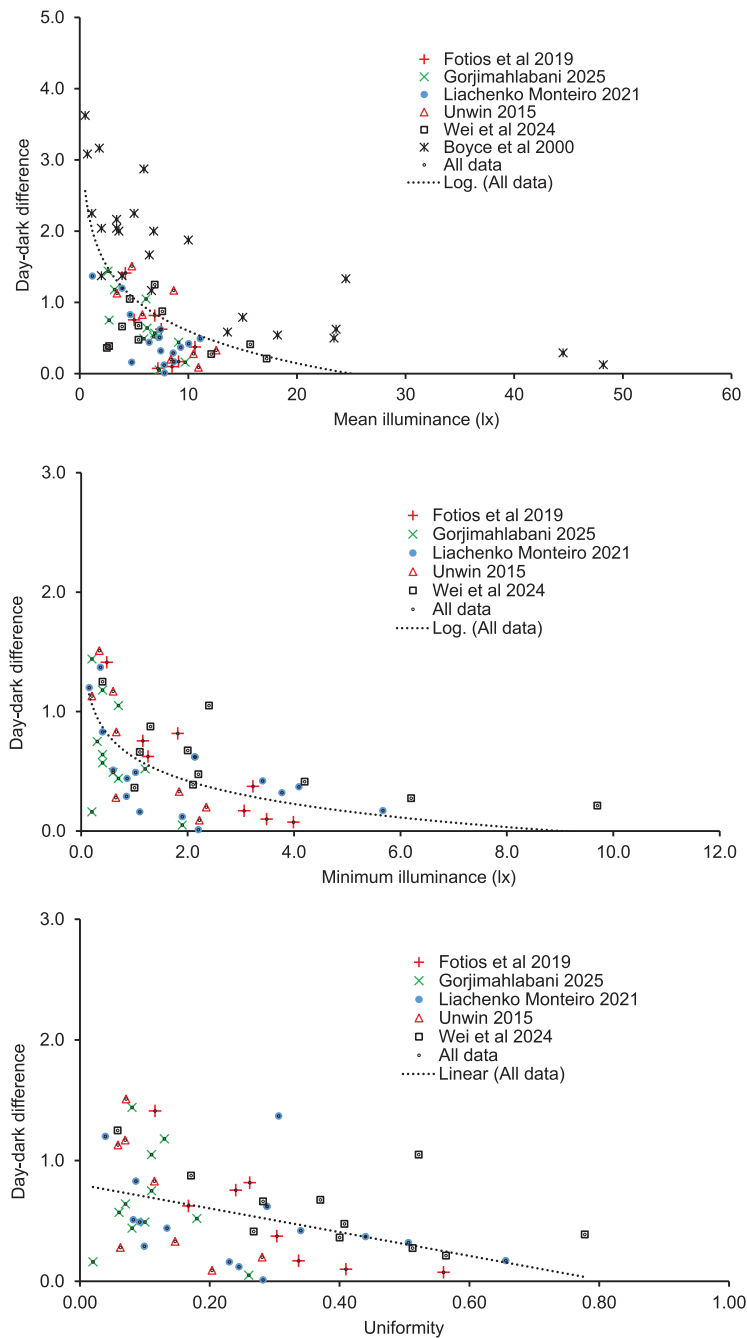


Figure 1 The day-dark difference in reassurance plotted against mean illuminance (*top*), minimum illuminance (*middle*) and uniformity of illuminance (*bottom*). In these graphs, a day-dark difference approaching 0 indicates good lighting – the difference between daylight and after-dark evaluations is minimised

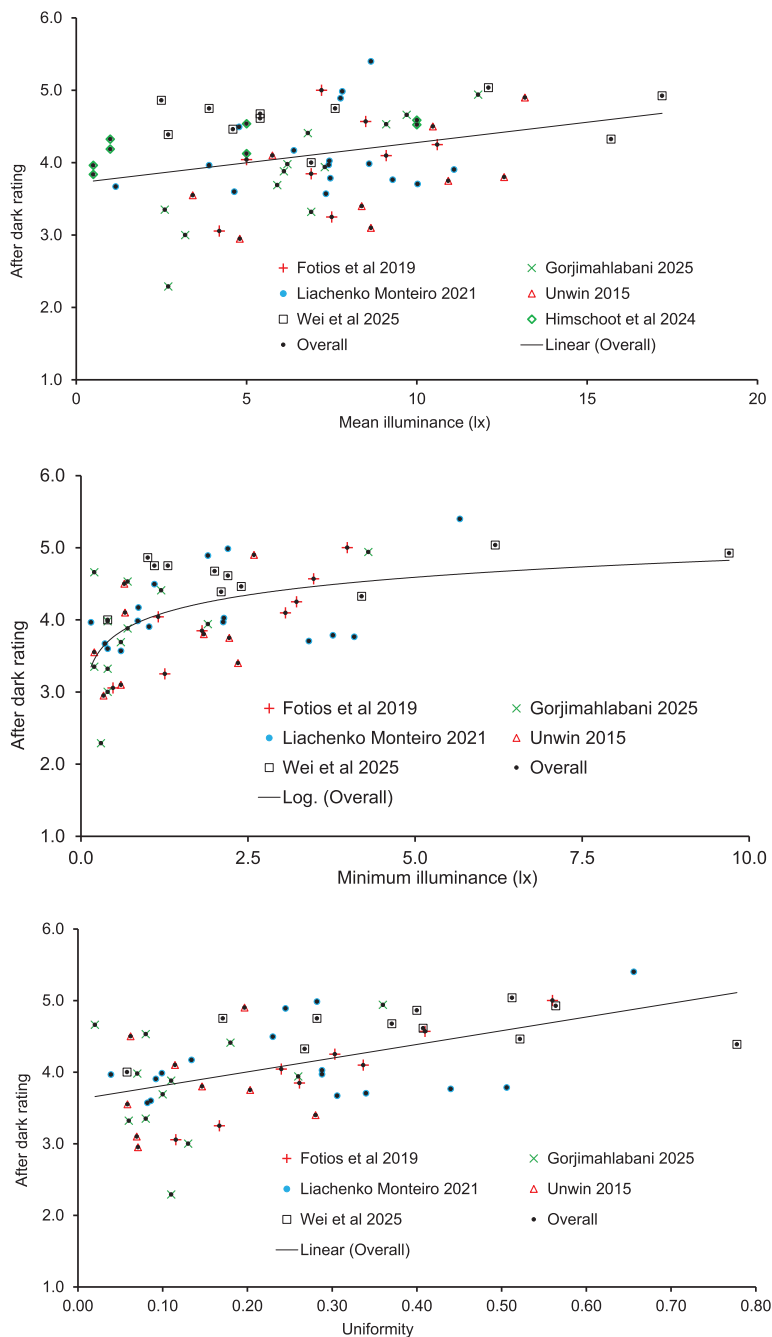


Figure 2 The after-dark rating of reassurance plotted against mean illuminance (*top*), minimum illuminance (*middle*) and uniformity of illuminance (*bottom*). In these graphs, a higher rating indicates a higher feeling of safety

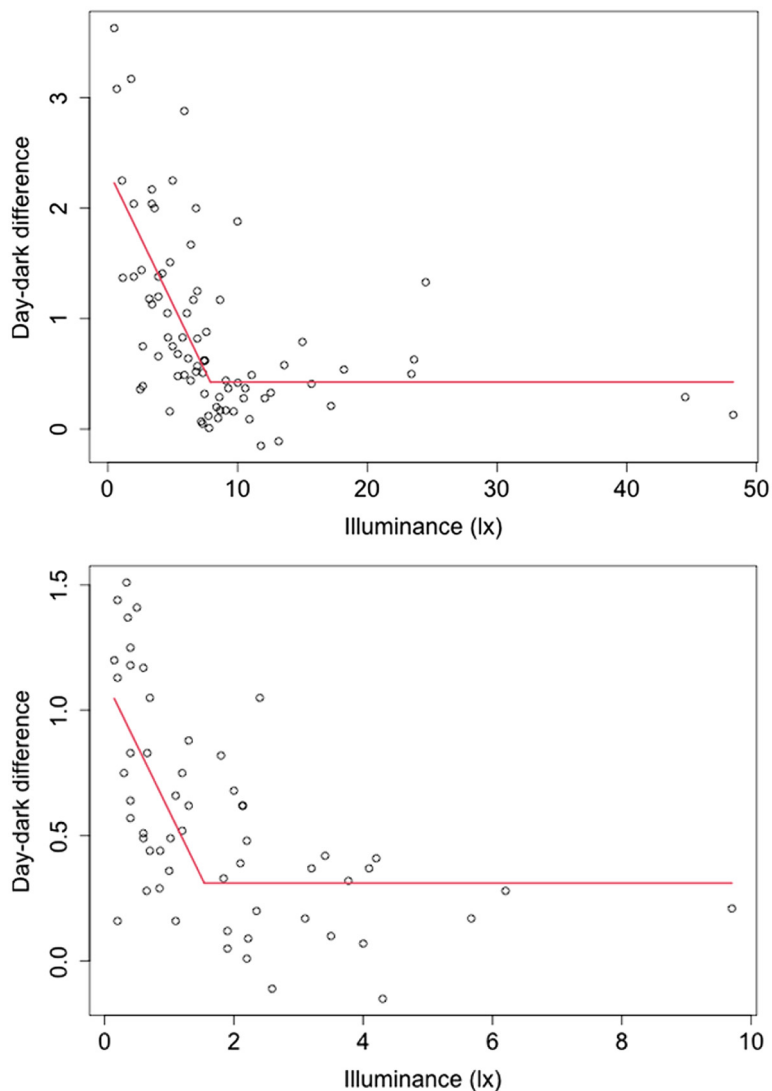


Figure 3 Segmented regression lines fitted to the day-dark difference and mean illuminance (*top*) or minimum illuminance (*bottom*)

4.2 Reasons to use different illuminances

Changes in context might suggest different illuminances are optimal. For example, in Figure 1 (*top*), which plots the day-dark difference against mean illuminance, the data points from the Boyce *et al.* study tend to lie above the best-fit line,

indicating a greater day-dark difference at that illuminance. This suggests that parking lots, the locations of that study, would benefit from higher illuminance. In Figure 2 (*top*), which plots after-dark reassurance against mean illuminance, the data points from Himschoot *et al.* tend to lie

above the best-fit line, indicating a greater feeling of safety: this suggests that in that location, a lower illuminance could be used.

These differences may be associated with the opportunities for concealment and entrapment. Concealment refers to hiding spots for potential offenders, such as bushes, walls and shadows; entrapment refers to physical features that impose a barrier to escape, and these will differ between open spaces and car parks. Narrow alleys are less likely to suggest good possibilities for escape and are therefore considered more dangerous than wide alleys.⁵² Blöbaum and Hunecke⁹ found in their field study that increasing the light level in areas of low entrapment led to a significant increase in reassurance, but in areas of high entrapment, the increased light level had relatively little effect.

For some situations, there is evidence to suggest that a higher light level would be beneficial.

- The detection of pavement hazards is hindered by the need to (or expectation to) conduct a face evaluation task in parallel, but this can be offset by a higher light level.⁵³ If the same impact of multi-tasking can be assumed for other visual tasks of pedestrians, then a higher light level would be beneficial in situations with higher cognitive demand, such as higher numbers of pedestrians, mixed-use routes, higher numbers of vehicles and more-hazardous pavement surfaces.
- Higher light levels can reduce the reaction time to detection of a target^{54–56} and may therefore offset the increased risk of a road traffic collision after dark on roads with a higher speed limit.^{57–60} However, while higher luminances are associated with decreased crash risk, including decreased risk of crashes involving a pedestrian, as was reported by Jacket and Frith,⁶¹ it remains to

be established whether higher luminances mitigate the increased risk of higher speeds.

- It has been shown that darkness deters walking and cycling.^{62–65} For cycling, it has been shown that the deterrent effect of darkness is reduced at higher light levels⁶⁶ and thus might be used as a means of promoting active travel, but that remains to be demonstrated for pedestrians.

In contrast, lower levels of road lighting may be suitable where the speed limit is less than 20 mph, where the footpath poses little likelihood of a trip hazard, in pedestrian-only footpaths, and where there are few other pedestrians or traffic.

Finally, while the weighting system of CIE 115:2010 assumes a cumulative effect for different weighting factors, this remains to be proven. It may be the case that changing the lighting class by one step may be sufficient mitigation for two (or more) risk factors appearing simultaneously, which would otherwise each prompt one step change, rather than needing to change the lighting class by two steps.

4.3 Limitations

Subjective measures of reassurance are prone to socially desirable responding⁶⁷ and other response biases.⁶⁸ Furthermore, as *stated* preferences, the extent to which they impact behaviour (the *revealed* preference) is unknown. While alternative approaches have been explored^{65,69,70} there are insufficient data available with these methods to demonstrate reproducibility and to identify optimal illuminance.

The data included in this analysis are limited by availability. For the analysis of day-dark difference and mean illuminance, the 80 overall locations are those reported in six studies, with those individual studies reporting evaluations of 8 to 24 locations by 18 to 122 test participants (Table 2). Furthermore, 45 of those locations

were in one city. It is suggested, however, that these data are suitable for the required rapid revision of CIE115:2010 for two reasons: (i) the data sources are revealed, meaning that others can test by replication the conclusions drawn and question the context relevance; and (ii) the sample of locations and observers is larger than those included in Simons *et al.*⁷¹ (12 locations evaluated by 13 people), which was considered sufficient evidence for the light levels recommended in BS5489-3:1992.⁷²

With these data, mean illuminance explains 42% of the variance in reassurance after dark (Table 4). Some of that variance can be ascribed to uncertainty in the measurements of illuminance and reassurance in the underlying studies – neither is easy to measure with precision. Further sources of variance may be associated with physical features of the environment, such as route width and the presence and proximity of greenery.^{52,73,74} Understanding the interaction between lighting and these other variables will help to identify where a change in light level is suitable.

5. Conclusions

Data from several studies of pedestrian reassurance were collated and analysed to determine an optimal lighting condition for P-class roads. It was found that using mean or minimum illuminance to predict the day-dark difference resulted in better relationships, these offering the highest R^2 values and were the only two cases for which segmented regression revealed a break point. Segmented regression suggested optimal illuminances of 8.76 lx (mean illuminance) and 1.54 lx (minimum illuminance). They are considered optimal because lower illuminances are associated with a decrease in reassurance, but higher illuminances bring no further increases in reassurance. To keep within the lighting classes of CIE115:2010, this suggests lighting class P3 (mean = 7.5 lx,

minimum = 1.5 lx) is optimal for pedestrian reassurance. Some situations are suggested where higher or lower illuminances might be suitable, but those changes remain to be verified.

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