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# ROAD LIGHTING AND PEDESTRIAN REASSURANCE AFTER DARK: A REVIEW OF THE EVIDENCE

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## Abstract

Road lighting is installed in residential areas is to increase pedestrians' reassurance, their confidence when walking after dark, which in past studies has been expressed as perceived safety or fear of crime. This article reviews past studies of road lighting and pedestrian reassurance to enable better understanding of whether lighting is effective, and of whether variations in illuminance and lamp type, are effective at improving reassurance. This review presents evidence that road lighting increases feelings of reassurance after dark, that higher illuminance increases this reassurance (and that it may be possible to identify a plateau to this effect) and that a higher S/P ratio enhances reassurance.

*Keywords*: e.g. road lighting, pedestrians, reassurance

## 1 Introduction

This article concerns the reassurance gained from road lighting in residential areas. In such areas it is normal to provide lighting that focuses more, but not exclusively, on the needs of pedestrians compared to those of drivers [CIE, 2010a]. Following previous use [DoE, 1994; Cozens et al, 2003] the term *reassurance* is used here to indicate confidence when using a road and is used here as an alternative for the perceived safety and fear of crime that have been used in previous studies: higher reassurance implies higher perceived safety and lower fear of crime.

One reason for investigating reassurance is that there is a link with walking decisions: a low level of reassurance can lead to constrained behaviour such as deciding to use an alternative means of transport to walking or to avoid going out at all. Walking is of wider interest because it is a common means by which physical activity can be introduced into people's daily routines in order to encourage good health [Loukaitou-Sideris, 2006]. The link between feelings of risk and fear and high levels of inactivity is particularly strong for women, children and the elderly [Loukaitou-Sideris, 2006]. In the US, estimates of clinical obesity based on clinical measurements indicate that (in 2000) one-third of the adult population are obese [Pucher & Dijkstra, 2003]. An increase in sedentary lifestyles and higher rates of obesity is concurrent with a steady decline in walking [Alfonzo, 2005]. Within North America and Europe, the US has the lowest percentage (7%) of trips in urban areas made by walking and cycling, followed by Canada (12%) and the UK (16%) while in Denmark and the Netherlands it is greater than 40% [Pucher & Dijkstra, 2003].

People's attitudes about walking are determined by beliefs about the likely consequences (e.g. health, injury) weighted by the evaluation of how good or bad these outcomes would be. Two types of risk that are of importance for pedestrians are the risk of being involved in an accident and the risk of being victim of criminal offences, violence or threats: in most cases it is the latter type of risk that is of importance for pedestrians, and which influences their behaviour [Fyhri et al, 2010].

A place will be considered unsafe (i.e. at risk of criminal offences, violence or threats) if it offers refuge to offenders and limited prospect and escape to potential victims [Fisher & Nasar, 1992]. These are physical features or an environment. It is important to perceive a potential danger as soon as possible [Blöbaum & Hunecke, 2005]: prospect is a measure of how well a person can look ahead to anticipate whom or what he/she is likely to encounter. Good prospect also implies that the pedestrian is visible to others. Escape is the opportunity for exit at various points along the path or in a location. Narrow alleys are considered more

dangerous than wide alleys [Herzog and Flynn-Smith, 2001] as they are less likely to suggest good possibilities for escape. Natural and artificial features along a route could provide a place to hide and these have dual possibilities, providing either a place for a potential attacker to wait out of sight (concealment) or a place for a potential victim to hide (refuge).

With regards to lighting and vision the influence of these physical features may considered under the categories of *visibility of others* and *visibility by others* [Luymes & Tamminga, 1995] raising questions such as *how much can I see?* and *how much am I seen?* [Greene & Greene, 2003]. People feel the safest if they have a good overview of the space in which they are moving and if they have the feeling that they are supported by other users [Greene & Greene, 2003]. Visibility of others, associated with prospect, is the ability to see ones surroundings clearly; the ability to appraise and recognise strangers; and the ability to survey visually approach directions and areas in close proximity to one's position. Visibility of others is related with refuge: people feel safer in cities when they are not isolated from contact with the larger urban realm. The ability to be seen allows casual surveillance by others who may defuse or be of assistance in threatening situations [Luymes & Tamminga, 1995].

Fear increases after dark because there are fewer people around, contributing to feelings of isolation from help if needed, and because visibility is reduced, which may provide offenders with more opportunities for concealment and may make it more difficult to identify escape routes should they be necessary [Dravitski et al, 2003]. Functionally, the most obvious and only certain effect better lighting can have is to change how well people can see: increasing the adaptation luminance increases the speed of visual processing, improves the discrimination of detail, makes colour judgements more accurate and increases the distance at which we can see anything suspicious [Boyce & Gutkowski, 1995]. Road lighting enhances vision after dark, thus we expect road lighting to improve the visibility of others and visibility by others, and thus to improve feelings reassurance compared with an unlit or poorly lit space. Thus road lighting has the potential to influence whether people choose to walk or cycle in their neighbourhood.

This paper presents a review of studies investigating the influence of road lighting on reassurance, a step toward establishing criteria for design guidance. The first studies reviewed are those which explore the influence lighting as a single entity and this is followed by investigations of two characteristics of lighting – illuminance and spectral power distribution (SPD).

## 2 Does lighting affect reassurance?

### 2.1 Evaluations of photographs

If light has an effect on reassurance, then a large difference in lighting conditions should lead to a large effect. This can be seen in the results from Loewen et al [1993] who compared photographs of scenes in daylight (with light) and at night-time (without light). Loewen et al presented 16 photographs, these being two different outdoor scenes for each of the eight combinations of light, open space, refuge, the items most frequently identified in their pilot study, for which participants were asked to provide ratings of items including safety. The results are shown in Figure 1. In all four situations regarding the presence or absence of open space and refuge, with-light was rated safer than without-light and this effect was larger than that found for differences in open space or refuge.

Hanyu [1997] sought judgements from 28 students regarding locations on their university campus (Ohio, USA), thus being evaluation of a familiar environment, using colour photographs observed in a dark classroom. There were 20 locations, for which photographs were taken at night-time, and were presented on a 6 feet x 5.5 feet (1.8 m x 1.7 m) screen in random order. Twelve items including brightness and uniformity were rated using a 5-point response scale (1 = not at all so; 5 = a great deal). Six emotional items including fear were rated on a 5-point bipolar scale (3 = neutral). The test duration was approximately 25 minutes for whole task and therefore these were rapid judgements. Hanyu's analysis suggested a relationship between safe and well-lit where well-lit included uniform lighting, legibility, complexity and brightness.

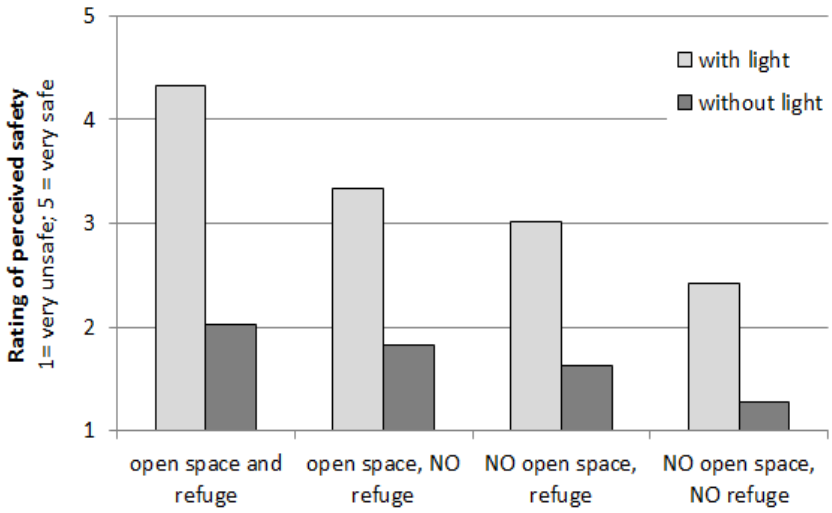


**Figure 1 – Mean ratings of perceived safety of images of outdoor scenes as reported by Loewen et al [1993].**

## 2.2 Evaluations of real locations

A potential limitation of the Loewen et al and Hanyu studies is that judgements made from observation of photographs of outdoor scenes do not give the same judgement as when made in the real location [Toet & van Schaik, 2012; Bishop & Rohrmann, 2003]. One approach to overcoming this is to obtain judgements whilst test participants are located in the real outdoor location. Painter [1994] surveyed pedestrians in three locations in London (Edmonton, Tower Hamlets, and Hammersmith and Fulham). In these three roads, the existing LPS lighting was replaced with HPS lamps, these installed to achieve an average of 10 lx (minimum 5 lx) while the original lighting provided less than 3.5 lx. Pedestrians were questioned about their experience within 5 minutes' walk of the location over the past 12 months. It was reported that "over 90% of pedestrians interviewed in all locations thought that fear of crime in the surrounding area had decreased" following installation of the HPS lighting although there is no statistical analysis. This suggests a change of lighting has effect, although it is not possible to determine whether it was the broader spectrum or higher illuminance of the HPS lighting that led to the apparent improvement in reassurance.

Okuda et al [2007] investigated attitudes to safety and security using a survey of local residents (n=249) carried out at night on streets in Hiroshima. A questionnaire sought identification of the roads and road features considered to be the most insecure and their opinion on what affects safety. The factors reported related to issues of lighting, presence of other people and traffic. Of these, dark street lighting and an empty street were the two most frequently mentioned by respondents (36%), followed by narrow street (25%) and no street light (20%). Note that the questionnaire was not presented in the report, and it is possible that it identified lighting as a potential factor, contributing to the frequency of responses identifying lighting as a factor.

Koga et al [2003] asked test participants to rate 32 items (including clean-dirty, light-dark, friendly-unfriendly) when stood in streets in Fukuoka, Japan. It was concluded that feelings of security increase in light and busy streets. Factor analysis derived five common factors from the evaluated items (liveliness, order, openness, intimateness, and unity) and lighting was essential to every factor. Three potential problems with this study are that the full set of questions and their analyses were not clearly reported, conclusions from some of the rated items may be misconstrued through translation, and the time of day at which ratings were made is not reported.

## 2.3 Evaluations from memory

Two studies surveyed large samples of people about outdoor locations likely to be familiar and reported effects of lighting. These responses were likely gained from residents whilst at

home and are therefore founded on their memory of the outdoor environment. Van Cauwenberg et al [2012] report a survey of 48,879 Belgian people aged >65 years old which included a question asking if street lighting was sufficiently present in the neighbourhood (Yes/No) and a series of rating scales to measure feelings of unsafety. The results suggested the presence of street lighting to increase feelings of safety and this was associated more with females than with males. It is not certain however whether judgements of sufficient street lighting relate to the presence/absence of street lighting or to the quantity (such as brightness) of some attribute of the lighting.

Bernhoft and Carstensen [2008] surveyed 1905 people (1017 older people aged >70 years old, 888 people aged 40-49 years old) in two Danish cities. One question asked "*Which of the following conditions are most important for your route choice when walking/cycling in your hometown*?" and respondents were asked to choose a maximum three of the eight given statements including 'Good street lighting'. While this was clearly not a direct question of reassurance, there may be an element of reassurance in decisions to walk and of which route to take [Fyhri et al, 2010] and these data provide insight as to the relative effect of lighting. The results are shown in Figure 2, these being the percentage of people identifying each of the eight statements. Bernhoft and Carstensen [2008] report the results for male and females separately; Figure 2 presents an estimated average of these (in only two case were the difference male and female responses suggested to be significant). Good street lighting was not the most frequent reason for route choice. For the younger age group, getting to the destination quickly and by the most direct route were more important; for the older group, all items were more frequently important than good street lighting. Note however that while it was possible to not pick good street lighting as a criterion for route choice, many did. It is of course possible that the importance of any of these eight issues was inflated simply by being presented as an option.

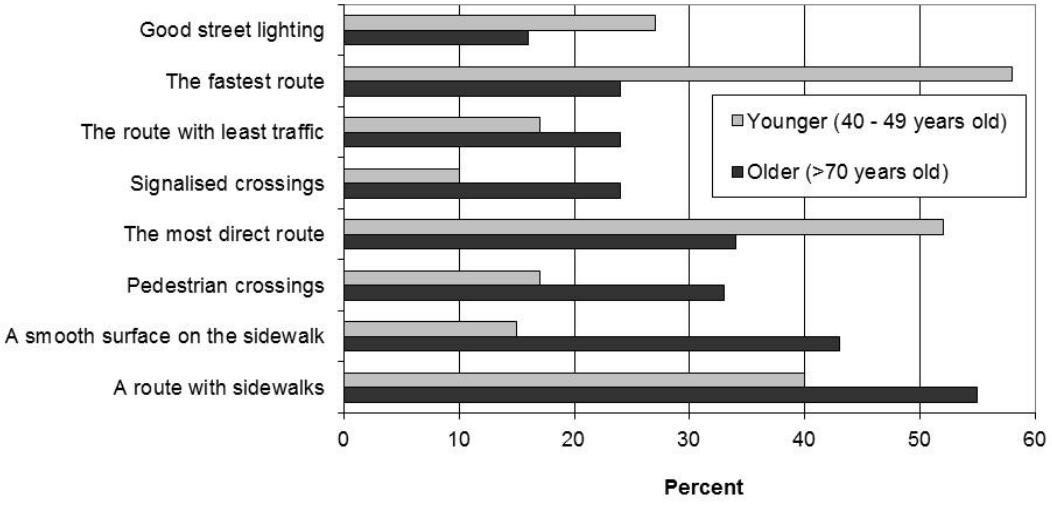


**Figure 2 – Conditions of importance for pedestrians route choice, from Bernhoft and Carstensen [2008].** Note: these values are estimated from their Figure 1 and are average values of the male and female responses presented.

## 2.4 Summary

Results from several studies suggest that lighting enhances, or is associated with, reassurance. While the evidence from any one particular study may be questioned, confidence is drawn from the convergence of conclusions gained by independent research groups using different stimuli and methods. Having drawn this conclusion, what is needed is an understanding as to how particular characteristics of lighting affect reassurance.

# 3 Illuminance

For a particular location, a higher illuminance will lead to a brighter environment. There is evidence that outdoor locations reported to be brighter will also be considered as safer

[Blöbaum & Hunecke, 2005] and thus higher illuminances are expected to enhance reassurance. This expectation was confirmed in three studies, these using different approaches to change between low and high illuminances. In the study by Matsui [2007], lighting that was normally dimmed to 30% output would increase automatically to 100% when a person approached the area. 82% of local residents reported that the higher illuminances gave them a greater sense of security. Vrij and Winkel [1991] sought ratings of safety from passing pedestrians before and after illuminance was increased by a factor of 5 in the test location (the increases were 0.1 lx to 0.5 lx on the bridge, 0.18 lx to 1.11 lx on the cycleway and 0.24 lx to 1.31 lx on the footpath). Atkins et al [1991] surveyed household before and after relighting in an urban area of the UK, providing a four-fold increase in illuminance (values not reported). It is likely there was a simultaneous change in lamp type but this is not clear. Surveys of local residents were administered before and after the relighting did not reveal a general increase in feelings of safety but did suggest a significant increase in safety amongst females.

Nair et al [1997] also investigated reassurance before and after changes to the lighting in a street in Glasgow, using a change in luminaire optics to increase average illuminance on the footway from 10 lx to 36 lx, but these results are not considered to be credible. One item asked how apprehensive the test participant had been that something unpleasant may have happened to them while walking along the street, and it appears that a 1-10 response scale was used for this item. The reported data imply a significant reduction in apprehensiveness, but there are reasons why this may not be a fair assessment. Responses were categorised as representing fearless, normal or timorous people, these being ratings of 1-2, 3-5 and 6-10 respectively. This uneven distribution of scores to assumed behaviour may not be a fair interpretation (and since the questions were not reported, this cannot be known for certain). It may be that collating ratings of 1-3, 4-7, and 8-10 would better represent fearless, normal and timorous people and may lead to a different interpretation of the data. Secondly, note that the targeted street was one that was generally considered to be unsafe at night-time and attracted unwelcome and unsavoury nocturnal activities, but which was used as it provided a useful short cut. The study also attempted to weight the results of the after survey (n=117) to match the gender profile of the before survey (n=102), and there are no data as to how this was done nor how it affected the results.

These studies suggest that higher illuminance enhances reassurance. A critical question for design is whether more illuminance will always be better or whether there is an optimum illuminance above which the increase in reassurance is negligible. Studies examining only two levels of illuminance provide insufficient evidence. Fortunately, there is one study [Boyce et al, 2000] that does provide evidence of an optimum illuminance, and this arises from the appraisal of several locations of different illuminance and from a novel approach to interpretation of the data.

Boyce et al [2000] carried out field surveys of 24 car parks in urban and suburban areas in New York and Albany in the US to investigate how the amount of light effected the perception of safety at night. Test participants were transported to the sites in four vehicles and these visited the sites in different orders at both daytime and night-time. At each site they were asked to walk around and then describe lighting using a series of semantic differential ratings scales including ratings of perceived safety when walking alone. As illuminances increased, the difference between ratings of perceived safety recorded at daytime and night-time tended to decrease (Figure 3). In other words, higher illuminances increased reassurance after dark towards the level experienced in daytime at that particular location. These data suggest an optimum horizontal illuminance of 10 lux; higher illuminances do not tend to improve reassurance at a particular location relative to the level of reassurance in daytime at that same location. Note, however, that the car parks surveyed had mean horizontal illuminances of up to 50 lux, higher than the 2.0 to 15 lux typically used in residential roads [CIE, 2010a] and thus there is a need to question if these data are appropriate.

In summary, there is evidence that road lighting of higher illuminance improves reassurance and furthermore, evidence that there may be a plateau to the effect [Boyce et al, 2000] thus allowing interpretation of an optimum illuminance.

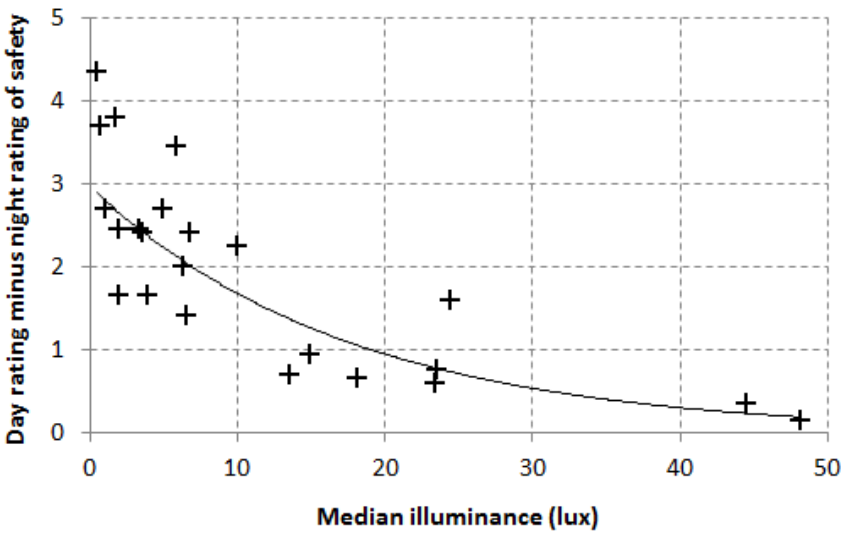


**Figure 3 – Difference between daytime and night-time ratings of perceived safety of car parks plotted against median illuminance, after Boyce et al [2000].**

## 4 Lamp spectrum

### 4.1 Field studies

Following the introduction of light sources such as metal halide (MH) for exterior lighting, informal assessment of trial schemes in the UK led some lighting practitioners to the opinion that these lamps, having broader SPD than traditional low pressure sodium (LPS) and high pressure sodium (HPS) lamps, presented benefits in visual perception and performance [ILE, 2008, Bennett, 2000]. While these trials tend to identify positive effects of improved lighting on reassurance the articles did not sufficiently describe details of the lighting installations, the people who were asked to give their judgements, the method by which judgements were obtained or the numeric data collected. This means the findings cannot be considered as reliable evidence or extrapolated to other situations.

A number of larger scale surveys have been carried out. While it would be expected that these provide more complete data, this is not always the case. Nair et al [1993] carried out before and after surveys following improvements to street lighting in a residential area. First, they fail to report the survey questions and the changes in lighting (lamp type and illuminance). The results include a reduction by 6% in the number of people worried about assault and harassment, although an increase by 9% in the number of people who avoided going out at all and an increase by 9% in the number of people who would avoid certain areas. However, the reported changes in opinions are not statistically analysed and the changes are small (e.g. 6% means two of the 33 respondents changed opinion). The results reported for one question serve to demonstrate the questionable validity of the Nair et al data; in the survey carried out before the lighting improvements had taken place, 17% of respondents reported recent improvement in lighting despite there being no such action (and in the after survey this was only 18%).

Three field studies present evidence that lamp SPD affects reassurance. In these, existing HPS lighting was replaced by lamps of broader spectral distribution and the environment evaluated by pedestrians using rating scales before and after the change. Morante [2008] surveyed two roads; in one, HPS lighting providing an average illuminance of 8.7 lx was replaced by QL lighting providing 2.7 lx; in the second road HPS lighting providing an average illuminance of 3.2 lx was replaced by MH lighting providing 3.1 lx. Akashi et al [2004] compared HPS street lighting with that from a 6500 K fluorescent lamp, these providing average photopic illuminances of 3.4 lx for the HPS lamp and 2.8 lx for the fluorescent lamp. In these two studies the lower photopic illuminances of the after lighting were chosen so that

the before and after lighting provided equal unified luminance [Rea & Bullough, 2007]. In the final study, Knight [2010] reported evaluations of the perception of brightness and safety before and after road lighting was changed from HPS to one of two types of MH (2800 K and 4200 K), with average illuminances in the given areas being similar before and after the change of lamp. In all three studies, the new lighting was found to provide higher ratings of safety than did the HPS, these differences being confirmed to be statistically significant in two studies [Akashi et al, 2004; Knight, 2010].

In any before and after study it is possible that respondents are responding to the attention being given to their local area, a Hawthorn-like response, rather than to a purposeful change in lighting characteristics. Alternatively, responses may be inflated by the high initial lumens of new lamps. The existing installation may have been near the end of its useful working life, with the inherent lamp failures, depreciated lumen output, and dirty lanterns, whilst the new installation was clean and benefited from the initial over-lighting included to offset subsequent lumen depreciation. However, if this initial response is the one that residents retain, that may be considered a useful contribution to resident satisfaction. An interesting feature of Knight's [2010] study is that a reverse change was included, in which the MH lighting was replaced with HPS lighting: the results suggest a statistically significant reduction in the perception of safety ($p<0.05$). What this result suggests is that the change in lighting matters. Further such evidence of a negative effect would be interesting.

## 4.2 Unpublished field studies

Fotios carried out two field studies of reassurance in collaboration with local authorities in the UK, taking advantage of their communications with residents during relighting schemes. One study was carried out in West Sussex and was reported in an ILE report [ILE, 2008]: the second study, carried out in South Tyneside, used the same procedure but was not previously published. Questionnaires were distributed to residents before and after the lighting in their street was changed. These questionnaires sought judgements of brightness, glare, perceived safety when walking alone at night and overall satisfaction. Ten questions required a yes/no response (e.g. it is safe to walk alone here, alone, during the day?; it is safe to walk alone here, alone, at night?) and there were two 10-point rating scales to evaluate brightness and overall satisfaction.

In South Tyneside, the existing low pressure sodium (LPS) lamps were replaced with Cosmopolis metal halide (CPO) lamps. The LPS lighting targeted an average illuminance of 6 lx (2.5 lx minimum; BS5489-3: 1992 category 3/2) and the new CPO lighting targeted 5 lx (1 lx minimum; BS5489-1:2003 class S4). 174 'before' questionnaires and 254 'after' questionnaires were received, of which there were 82 matched pairs as identified by household address and these results are shown in Table 1. Questions 1 to 10 demanded a yes/no response and these were analysed using McNemar's test: questions 11 and 12 asked respondents to rate the brightness of the street and their satisfaction with the lighting on a 1 to 10 scale and these were analysed using the Wilcoxon test. These results suggest that the new CPO lighting was considered to be better than the existing LPS lighting despite that it was designed to provide a lower illuminance: there was an increase in perceived safety at night-time and other attributes including brightness and overall satisfaction.

In West Sussex the 35W LPS lamps in a residential estate were replaced with 55W CFL lamps [ILE, 2008]. The same spacing was used (30m) and column height was increased from 5m to 6m. The LPS lamps gave a mean illuminance of 4.7 lux and an illuminance uniformity (minimum to average) of 0.26: the CFL lamps provided a mean illuminance of 4.9 lux and a uniformity of 0.32 (data provided by the local authority). Thus other than lamp type, differences between the two installations were small. The change in lighting did not affect judgements of safety when walking alone at day or night and did not affect judgements of comfort or glare. What the change in lighting did affect were judgements of visibility, uniformity and colour. Compared to the original LPS lighting the CFL lighting was considered to be significantly brighter, more uniform, better illuminated the whole street and distant people, and revealed colours better. Both brightness and satisfaction were significantly higher under the new CFL lighting.

**Table 1 – Results of lighting survey in South Tyneside; results from the 82 matched pairs. For questions 1-10 the reported response is the number of 'yes' responses. For questions 11 & 12, the reported response is the mean rating**

| Question | | Response to Questionnaire | | | Interpretation |
|---|---|---|---|---|---|
| | | Before (LPS) | After (CPO) | Statistical difference | |
| Q1 | It is safe to walk here, alone, during the day. | 77 | 80 | n.s. | No change in perceived safety at day |
| Q2 | It is safe to walk here, alone, at night. | 32 | 61 | p<0.01 | Better perceived safety with CPO at night |
| Q3 | The lighting is comfortable. | 41 | 71 | p<0.01 | Better comfort with CPO |
| Q4 | The lighting shows up the whole street well. | 30 | 68 | p<0.01 | CPO shows up street better |
| Q5 | The lighting lets me see people at a distance, clearly. | 25 | 65 | p<0.01 | Can see distant people better under CPO |
| Q6 | The lighting is too bright. | 3 | 4 | n.s. | No change |
| Q7 | The lighting is too dark. | 45 | 9 | p<0.01 | Increase in brightness |
| Q8 | The lighting is uneven (patchy). | 45 | 19 | p<0.01 | CPO is less uneven |
| Q9 | The lighting is glaring. | 6 | 4 | n.s. | No change in glare |
| Q10 | The lighting does show colours properly. | 21 | 61 | p<0.01 | Better colour appearance under CPO |
| Q11 | Now, using a scale of 1 to 10, please rate how bright the street lighting is (1 = very dark, 10 = very bright). | 5.5 | 7.9 | p<0.01 | CPO is brighter |
| Q12 | Now, using a scale of 1 to 10, please rate how satisfied you are with the lighting (1 = very dissatisfied, 10 = very satisfied). | 5.4 | 8.4 | p<0.01 | CPO gives higher satisfaction |

### 4.3 S/P ratio

At mesopic levels of adaptation lighting from lamps of higher S/P ratio tends to appear brighter, for example scenes lit by lamps such as MH and fluorescent appear brighter than when lit by HPS lamps of equal illuminance [Fotios & Cheal, 2007, 2011], and thus lighting of higher S/P ratio may also enhance reassurance. The S/P ratio is an interesting metric for outdoor lighting, providing characterisation of visual performance [CIE 2010b] in addition to spatial brightness [Fotios & Cheal, 2011] and is the basis of new road lighting guidance in the UK [Fotios & Goodman, 2012: ILP, 2012]. There is evidence that higher S/P ratio enhances reassurance in the results of the field studies described above where existing LPS or HPS lighting was replaced by lamps of broader spectral distribution [Akashi et al, 2004; Knight, 2010; Morante, 2008].

## 5 Conclusion

This review sought to establish evidence of how lighting characteristics may influence pedestrians reassurance when walking after dark. There is some evidence that lighting is associated with reassurance by pedestrians [Painter, 1994, 1996; Okuda et al, 2007; Koga, 2003; Van Cauwenberg et al, 2012, Bernhoft & Carstensen, 2008; Hanyu, 1997]. There is evidence that illuminance [Boyce et al, 2000; Vrij & Winkel, 1991] and SPD [Akashi et al, 2004; Knight, 2010; Morante 2008] matter. Pedestrian reassurance is enhanced by lighting that is brighter. This brightness can be achieved using higher illuminance and/or higher S/P ratio. For illuminance, at least, there is some evidence that there may be a plateau (10 lux) beyond which further increase in illuminance does not lead to significant increase in reassurance [Boyce et al, 2000] but that evidence requires confirmation in the context of residential roads. This article has not addressed the spatial distribution of light: there is insufficient evidence regarding the effect of illuminance uniformity but there is some evidence that lighting the immediate vicinity of a pedestrian and natural objects enhances reassurance [Haans & de Kort, 2012; Nikunen & Korpela, 2012].

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## References

AKASHI, Y., REA, M., MORANTE, P. 2004. Progress Report: Improving acceptance and use of energy-efficient lighting. Unified photometry: An energy-efficient street lighting demonstration in Easthampton, Massachusetts. Lighting Research Center. USA: Troy.

ALFONZO, MA. 2005. To walk or not to walk? The hierarchy of walking needs. *Environment & Behavior*, 37; 808-836.

ATKINS, S., HUSAIN, S., STOREY, A. 1991. The Influence of Street Lighting on Crime & Fear of Crime. Paper 28, Crime Prevention Unit. London.

BENNETT, R. 2000. White light reduces fears. *The Philips Lamp & Gear Magazine*, 3(2); 14-17.

BERNHOFT, I.M., CARSTENSEN, G. 2008. Preferences and behaviour of pedestrians and cyclists by age and gender. *Transportation Research Part F*, 11; 83–95.

BISHOP, ID., ROHRMANN, B. 2003. Subjective responses to simulated and real environments: a comparison. *Landscape and Urban Planning*, 65; 261-277.

BLÖBAUM, A., HUNECKE, M. 2005. Perceived danger in urban public space. The impacts of physical features and personal factors. *Environment and Behaviour*, 37(4); 465-486.

BOYCE, PR., EKLUND, NH., HAMILTON, BJ., BRUNO, LD. 2000. Perceptions of safety at night in different lighting conditions. *Lighting Research & Technology*, 32; 79-91.

BOYCE, PR., GUTKOWSKI, JM. 1995. The if, why and what of street lighting and crime: A review. *Lighting Research and Technology*, 27(2); 103-112.

VAN CAUWENBERG, J., CLARYS, P., DE BOURDEAUDHUIJ, I., VAN HOLLE, V., VERTÉ, D., DE WITTE, N., DE DONDER, L, BUFFEL, T., DURY, S., DEFORCHE, B. 2012. Physical environmental factors related to walking and cycling in older adults: the Belgian ageing studies. *Public Health*, 12; 142.

CIE. 2010a. CIE 115:2010. Lighting of Roads for Motor and Pedestrian Traffic. Vienna: CIE

CIE. 2010b. CIE 191:2010. Recommended system for visual performance based mesopic photometry. Vienna: CIE.

COZENS, PM., NEALE, RH., WHITAKER, J., HILLIER, D., GRAHAM, M. 2003. A critical review of street lighting, crime and fear of crime in the British city. *Crime Prevention & Community Safety: An International Journal*, 5(2); 7-24.

Department of the Environment and Welsh Office. 1994. Planning Out Crime Circular 5/94. Crown Copyright: London.

DRAVITZKI, VK., CLELAND, BS., WALTON, D., LAING, JN. 2003. Measuring commuting pedestrians' concerns for personal safety and the influence of lighting on these concerns. 26th Australasian Transport Research Forum. Wellington, New Zealand. 1-3 October, 2003.

FISHER, BS., NASAR, JL. 1992. Fear of Crime in Relation to Three Exterior Site Features : Prospect, Refuge, and Escape. *Environment and Behavior,* 24(1); 35-65.

FOTIOS, SA., CHEAL, C. 2011. Predicting Lamp Spectrum Effects At Mesopic Levels. Part 1: Spatial Brightness. *Lighting Research & Technology*, 43(2); 143-157.

FOTIOS, SA., CHEAL, C. 2007. Lighting for subsidiary streets: investigation of lamps of different SPD. Part 2 – Brightness. *Lighting Research & Technology*, 39(3); 233-252.

FOTIOS, S., GOODMAN, T. 2012. Proposed UK Guidance for Lighting in Residential Roads. *Lighting Research & Technology*, 44(1); 69-83.

FYHRI, A., HOF, T., SIMONOVA, Z., DE JONG, M. 2010. The influence of perceived safety and security on walking. Walk21; Getting communities back on their feet. Den Haag, Netherlands, 16-19 November 2010. 49-70.

GREENE, M., GREENE, R. 2003. Urban safety in residential areas: Global spatial impact and local self-organising processes. 4th International Space Syntax Symposium London 2003. pp52.1-52.8

HAANS, A., DE KORT, YAW. 2012. Light distribution in dynamic street lighting: Two experimental studies on its effect on perceived safety, prospect, concealment, and escape. *Journal of Environmental Psychology*, 32; 342-352.

HANYU, K. 1997. Visual properties and affective appraisals in residential areas after dark. *Journal of Environmental Psychology*, 17; 301-315.

HERZOG TR AND FLYNN-SMITH JA. 2001. Preference and perceived danger as a function of the perceived curvature, length and width of urban alleys. *Environment and Behavior*, 33; 653-666.

ILE. 2008. TR29: White Light. Rugby: ILE.

ILP. 2012. PLG03:2012. Lighting for Subsidiary Roads: Using white light sources to balance energy efficiency and visual amenity. Rugby; ILP.

KNIGHT, C. 2010. Field surveys investigating the effect of lamp spectrum on the perception of safety and comfort at night. *Lighting Research & Technology*, 42(3); 313-330.

KOGA, Y., TANAKA, R., SHIBATA, D. 2003. Evaluation structure on night streets. A case study in Fukuoka. 25th Session of the CIE. San Diego, 25 June to 2 July 2003. ppD5 82-85

LUYMES DT, TAMMINGA K. Integrating public safety and use into planning urban greenways. Landscape and Urban Planning, 1995; 33; 391-400.

LOEWEN, LJ., STEEL, GD., SUEDFELD, P. 1993. Perceived Safety from Crime in the Urban Environment. *Journal of Environmental Psychology*, 13, 323-331.

LOUKAITOU-SIDERIS, A. 2006. Is it Safe to Walk?1 Neighborhood Safety and Security Considerations and Their Effects on Walking. *Journal of Planning Literature*, 20: 219-232.

MATSUI, T. 2007. A study on a street lighting that makes change illuminance is effective for both reducing fear of crime and saving energy. 26th Session of the CIE, pp D5-112 – D5-115. China: Beijing

MORANTE, P. 2008. Mesopic street lighting demonstration and evaluation. Final Report for Groton Utilities, Groton, Connecticut. Lighting Research Center. USA: Troy.

NAIR, G., MCNAIR, DG., DITTON, J. 1997. Street lighting: Unexpected benefits to young pedestrians from improvement. *Lighting Research & Technology*, 29(3); 143-149.

NAIR, G., DITTON, J., PHILLIPS, S. 1993. Environmental improvements and the fear of crime. *British Journal of Criminology*, 33,4, 555-561.

NIKUNEN, H., KORPELA, KM. 2012. The effects of scene contents and focus of light on perceived restorativeness, fear and preference in nightscapes. *Journal of Environmental Planning and Management*, 55(4); 453-468.

OKUDA, S., ISHII, J., FUKAGAWA, K. 2007. Research on the lighting environment in the street at night. Part 1. Resident's attitude on the safety and security in the street at night. 26th session of the CIE, Beijing, July 2007.

PAINTER, K. 1994. The impact of street lighting on crime, fear and pedestrian street use. *Security Journal*. 5(3); 116-124.

PUCHER, J., DIJKSTRA, L. 2003. Promoting safe walking and cycling to improve public health: Lessons from the Netherlands and Germany. *American Journal of Public Health*, 93(9); 1509-1516.

TOET, A., VAN SCHAIK, MG. 2012. Effects of signals of disorder on fear of crime in real and virtual environments. *Journal of Environmental Psychology*, 32; 260-276.

VRIJ, A., WINKEL, FW. 1991. Characteristics of the built environment and fear of crime: a research note on interventions in unsafe locations. *Deviant Behavior: An Interdisciplinary Journal*, 12; 203-215.