Investigation of Lighting Levels for Pedestrians

-Some questions about lighting levels of current lighting standards-

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Abstract

In order to find out appropriate lighting levels to create safe nighttime street environments, the nature of the relationships between pedestrian behaviour and lighting (illuminance) levels was explored using the PAMELA facility at University College London. The behaviour examined was the avoidance of collision with another pedestrian or an obstacle, and the facial recognition distance and the interpersonal distance required to feel comfortably secure. A pilot experiment was set up, in which the behaviour of ten participants was tested under illuminance of 0.67, 2.8, 5.5, 12.3 and 627 lux. Results showed that only facial recognition distance has a proportionate relationship to the illuminance levels. It was also found that in order to provide facial recognition when a pedestrian starts a collision avoidance manoeuvre, more illuminance than today's lighting standard is necessary. It is suggested to reconsider what tasks are necessary for pedestrians at nighttime, and that the illuminance level of each street should be based on assumed tasks undertaken by pedestrians, rather than car traffic, on each street.

Biographies

Taku Fujiyama is a research fellow at Centre for Transport Studies, University College London. His background is Transport Engineering, where he has specialised in the design of railway stations in Japan. His research interest is in accessibility of public transport facilities and systems and their evaluation, especially in relation to the needs of pedestrians in public.

Craig Childs is a research fellow at Centre for Transport Studies, University College London. He obtained his PhD in Biomedical Science and Engineering from the Aalborg University, Denmark. His recent research focuses on human movements; in particular, accessibility in pedestrian environments.

Derrick Boampong is a project member of PAMELA at Centre for Transport Studies, University College London. He obtained his PhD in Biomedical Engineering from the University of Durham, UK, and is interested in walking and its implications in Biomedical Engineering.

Nick Tyler is Chadwick Professor of Civil Engineering at University College London and the head of the department of Civil and Environmental Engineering. He also leads the Accessibility Research Group at UCL. His research focus ranges from the ethical and philosophical principles behind policy making to the study of the interactions between people and systems, to the design and implementation of infrastructure and operating systems. He instigated and designed the Pedestrian Accessibility and Movement Environment Laboratory.

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Introduction

Safe environments for walking at night are essential to promote more walking. Creation of such safe environments also contributes to more creation of walking culture. On the contrary, much research on creation of safe walking environments has tended to focus on walking in the daytime, and thus far little attention has been paid to walking environments at nighttime. It is assumed that, at nighttime, people become more sensitive to approaching persons or objects in the interests of safety. On the other hand, the amount of visual information that people can gather decreases because of low illuminance. In order to create a more walkable city, more attention should be given to walking environments at nighttime, especially to creation of safe environments.

It is imperative to understand the behaviour and perception of pedestrians in dark conditions in order to realise safe walking environments for the nighttime. This paper focuses on the extent to which lighting affects the behaviour and perception of pedestrians. This is because the increase of the lighting level is an effective way to improve walking environments at nighttime.

The origin of today's standards for street lighting in residential areas was established in the 1980's. Since then, there has been much progress in not only understanding of behaviour and perception of people but also technologies for lighting. It would be of value to review and update the background of lighting standards.

Following a brief review of the background of lighting standards, this paper describes an experiment set up in the Pedestrian Accessibility and Movement Environment laboratory (PAMELA) at UCL to explore how people act under different lighting conditions. The paper then suggests some ideas about lighting design for safe walking environments.

Lighting standards for pedestrians and recent relevant studies

Lighting standards for pedestrians have been almost a by-product of lighting standards for car traffic. The reason may be that driving a car is thought to require harder tasks in terms of visual perception than is acting as a pedestrian, yet the lack of understanding of pedestrian needs and their behaviour may lead to a situation where the pedestrian's tasks are made unreasonably difficult because of a lack of visual acuity. Nevertheless, there are some standards for street lighting for pedestrians. Table 1 shows the requirements for road lighting in British Standards (BS EN 13201-2:2003), which incorporate the European Standards. For conflict areas such as shopping streets and road intersections of some complexity, or for roads whose crime risk is higher than normal, a higher level of illuminance is often adopted.

Table 1. Requirements for road lighting for pedestrians by BS EN 13201-2:2003[1]

Class	Horizontal illuminance (lux)	
	Average	Minimum
S1	15	5
S2	10	3
S3	7.5	1.5
S4	5	1
S5	3	0.6
S6	2	0.6
S7	-	-

Note: S classes are for pedestrians and pedal cyclists for use on footways and cycleways, emergency lanes and other road areas lying separately or along the carriageway of a traffic route, residential roads, pedestrian streets, parking areas, schoolyards, etc. (British Standards Institute (2003))

In the UK, it is local governments that decide a lighting class for each road by taking account of its traffic volume, the number of crime incidents, environments and so forth. Before the introduction of BS EN 13201-2:2003, lighting levels for pedestrians were regulated by BS 5489-3.

Table 2. Requirements for road lighting for pedestrians and pedal cyclists by BS 5489-3

Class	Horizontal illuminance (lux)	
	Average	Minimum
3/1	10	5
3/2	6	2.5
3/3	3.5	1

Note: 3/x classes are for subsidiary roads, namely access roads, residential roads, and associated pedestrian areas, where pedestrian is the main traffic. (British Standards Institute (1992))

How were these lighting levels for pedestrians defined? According to Raynham and Saksvikrønnig (2003), British standards (BS) 5489 part 3 “code of practice for subsidiary roads and associated pedestrian areas” was based on Caminada and Bommel (1980). They suggested that, for lighting for pedestrians, the following tasks be taken into account: detection pf obstacles; visual orientation; and facial recognition of other pedestrians. Among these, facial recognition requires the most illuminance. Referring to a personal space study by Hall (1966), Caminada and Bommel insisted that lighting ensure identification of a face at a distance of 4 m. 4 m is the minimum value that brings comfort with regard to normal social contact (Bommel and Caminada (1982)), where an alert subject can take evasive or defensive action if threatened. By means of an experiment, Caminda and Bommel found that a value for semi-cylindrical illuminance[2] of 1 lux, which is roughly equivalent to a value for horizontal illuminance of 5 lux, enables facial recognition at a distance of 4 m. This result became a basis for BS 5489. It is speculated that BS EN 13201-2:2003 also adopted this idea.

Questions that may be raised are
1) Is 4 m an adequate distance also in dimmed conditions? and
2) Should facial recognition be the decisive factor for street lighting? Are there any other factor to be considered?

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[1] Lighting levels are described by illuminance, whose unit is lux. Illuminance is the quantity of lighting arriving on a unit area of a surface, and used for description of lighting levels in most of the standards.

[2] Horizontal illuminance (E_{sc}) is the illuminance on a flat surface (in this case, the surface of the road). Semi-cylindrical illuminance is the illuminance on the curved surface of an infinitely small vertical half-cylinder. Bommel and Caminada found that E_{sc} was well correlated to the facial recognition distance.

A later personal space study conducted by Adams and Zuckerman (1991) found that an interpersonal distance necessary to maintain comfort becomes larger in a dimmed condition. Also, Hall (1966) himself pointed out variance of the size of personal space according to personality and environmental factors, such as low illumination.

Moreover, it should be examined whether or not this 4 m is appropriate for (moving) pedestrians, who simultaneously perceive the environment and move their bodies. It is conjectured that the personal space of pedestrians in motion differs from that of stationary people.

According to recent studies, there may be two mechanisms operating in crime reduction by enhanced lighting. One is the situational control model, where increased visibility obtained by enhanced lighting deters potential offenders from committing crime The other is the community pride model, where enhanced lighting attracts more attention of residents to their neighbourhood, and consequently community pride, community cohesiveness and informal social control are achieved. Such situations discourage potential offenders from carrying out crime (Farrington and Welsh (2002)). Interestingly, neither theory includes (one to one) facial recognition by possible victims as a part of the mechanism. It should be noted that both hypotheses emphasise the importance of visibility in street environments. In particular, the former factors in the visibility of pedestrians to residents (facial recognition to unspecified people).

Target of this research

The purpose of this research is to investigate how illuminance affects perception and behaviour of pedestrians. This is of value for understanding what should be considered when designing lighting for pedestrians. As the first step of a series in this research, an experiment was conducted to examine how simple pedestrian movements, mainly avoidance behaviour in relation to another pedestrian or an obstacle, are affected by illuminance. This simple avoidance behaviour may reflect the perception and reaction of pedestrians to surrounding environments. Although the experiment was a pilot to determine methods, parameters and ranges for more extensive experiments, the data obtained could be of use inasmuch as suggesting some qualitative features, which may help produce recommendations for the design of lighting or lighting standards.

PAMELA laboratory

The empirical work took place in the Pedestrian Accessibility and Movement Environment Laboratory (PAMELA) at University College London, where the lighting configuration can be controlled and easily altered.

PAMELA is a laboratory used to simulate existing and proposed pedestrian environments. There are several elements of the laboratory, perhaps the most obvious being a computer-controlled paved platform which can be varied in terms of layout, topography and surface type. This allows existing “open space” accessibility issues to be rigorously examined under controlled conditions. It also enables infrastructure designs to be checked, thereby avoiding the possibility of costly mistakes on-site arising from a subsequent accessibility audit. The laboratory is also equipped with a lighting system. It is possible to vary features such as different lighting levels, the layout of the platform, surface material, colour and texture, gradients, step heights and the positions of obstacles.

The lighting system is capable of representing lighting conditions from absolute darkness to near-daylight, including various levels and colours of artificial lighting. Part of the lighting system is installed on a mobile lighting gantry to allow us to vary lighting in terms of position. Floodlights that provide strong shadow contrasts are among the lighting facilities.

Fig. 1 PAMELA laboratory

Experiment

Method

The configuration of the laboratory used in the experiment is shown in Fig 2. The experiment comprised four measurements: collision avoidance behaviour between pairs of pedestrians; obstacle avoidance behaviour of pedestrians; facial recognition distance; minimum comfortable distance. Each measurement was performed under five different lighting conditions: about 627, 12.3, 5.5, 2.8 and 0.67 lux measured at ground level on the surface of the platform (horizontal illuminance). Lighting resources were fluorescent lamps, but for 627 lux ceramic discharge lamps were also used. These lighting levels were chosen to investigate alteration of pedestrian behaviour according to lighting levels, especially around the requirements of the current lighting standards for the residential streets (See Table 1). The surface of the platform was covered by 40 cm square concrete blocks without any surface colour modification. It was therefore easy to determine the positions of participants by observing which tile a participant occupied at a given point in time. In total, ten people participated. The participants consisted of five males and five females, aged from 25 to 65. Three participants wore glasses. All participants underwent an eye test[3] in advance for comparative as well as health and safety reasons. Details of each experiment are given below. Illuminance levels were measured by Minolta T-10 illuminance meter.

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[3] Visual acuity test using a LogMAR chart. Every participant showed a score of 0.1 or less.

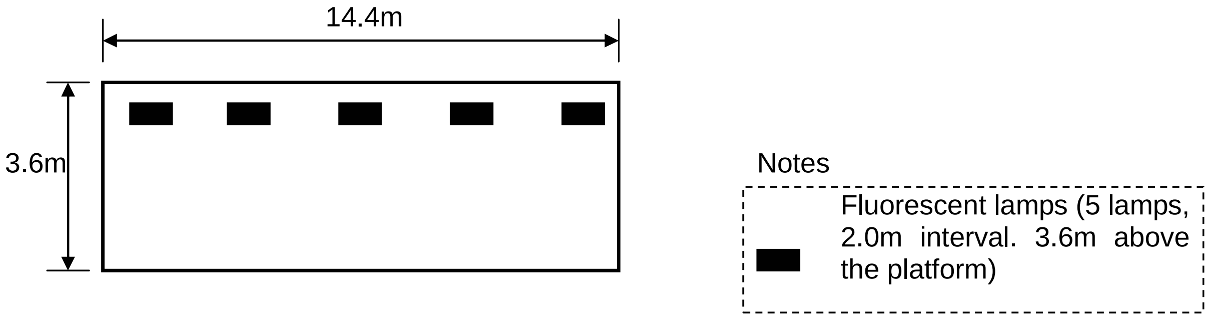


Fig.2 Experiment site (ground plan)

In this experiment, the platform (surface of the ground) was flat.

Collision avoidance distance measurement

One of each pair of participants was asked to stand at either end of the platform. Both participants were then asked to start walking at the same time towards a target mark on the opposite side of the site from their starting point. When he/she reached the other end of the platform, he/she stopped walking (See Fig.3). While they were heading towards the target, participants were allowed to see other objects than the target and to step aside. Because the pair of participants and the target marks are on a straight line, participants had to avoid collision with each other (although this was not especially mentioned in the instructions given to participants prior to the measurement). Pairs of participants were randomly selected. Experimenters recorded where participants began to deviate from their path in order to avoid the other participant. The distance between the two points at which each participant started their avoidance manoeuvre, was calculated thereafter. This procedure was repeated four times for each of the five illuminance levels used in the experiment.

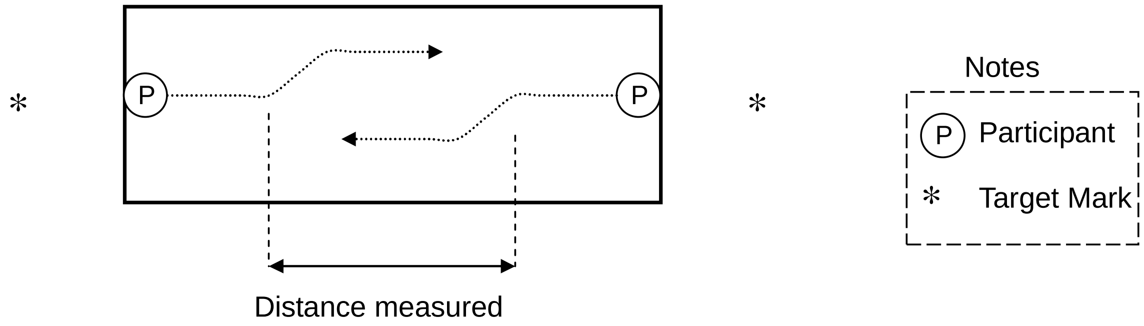


Fig.3 Collision avoidance measurement (ground plan)

Obstacle avoidance distance measurement

Each participant was asked to walk from one side of the site to the other side. However, an obstacle with a height of 1.50m and a width of 0.51m was placed in the middle of the site, so that each participant had to avoid the obstacle to reach the other side (See Fig.4). The obstacle is a simple representation of a stationary person, and its shape is shown as Fig. 5. Again, the instruction to participants beforehand did not include the avoidance. An experimenter recorded where each participant started avoidance. The distance between the obstacle and the point, where the participant started avoidance, was calculated thereafter. This procedure was repeated four times for each five illuminance levels.

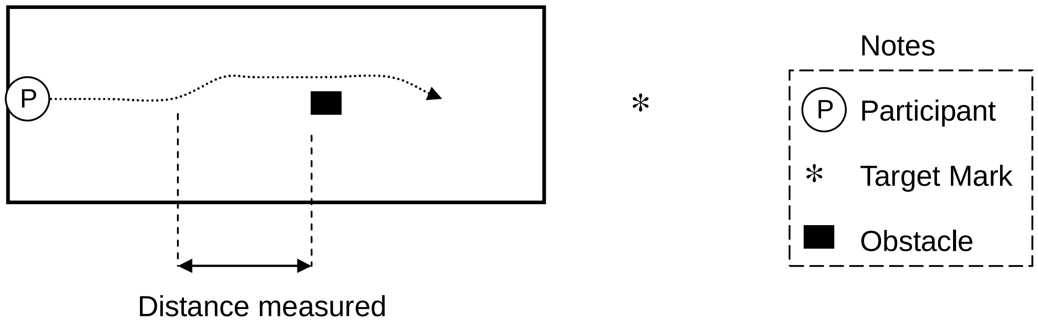


Fig.4 Obstacle avoidance measurement (ground plan)

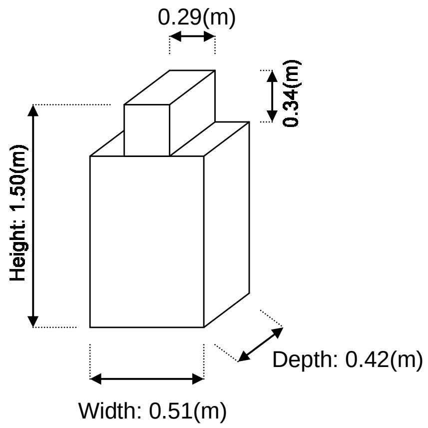


Fig.5 Obstacle used in the obstacle avoidance measurement

Facial recognition distance measurement

Facial recognition distance of participants was also measured. In this case, each participant was asked to walk slowly from one side of the experiment site towards an experimenter, who stood at the other side of the site. In order to ensure that the participant recognised the experimenter only by means of their face, the experimenter wore a helmet and stood behind a screen so that they were only visible to the participant from the chin upwards, the helmet obscuring details such as hair style etc. In this way, other characteristics, such as height, would not influence their recognition of the experimenter. The participant was then required to stop when he/she FIRST thought that they could identify the experimenter. After a target mark was placed at the point where the participant stopped, the participant was asked to walk again and stop when this time he/she SURELY recognised the face of the experimenter (See Fig.6). The distances were measured between the experimenter and the two points, namely where the participant recognised the experimenter’s face AT FIRST (first recognition) and where the participant SURELY recognised the experimenter’s face (sure recognition). This procedure was repeated under the five lighting levels.

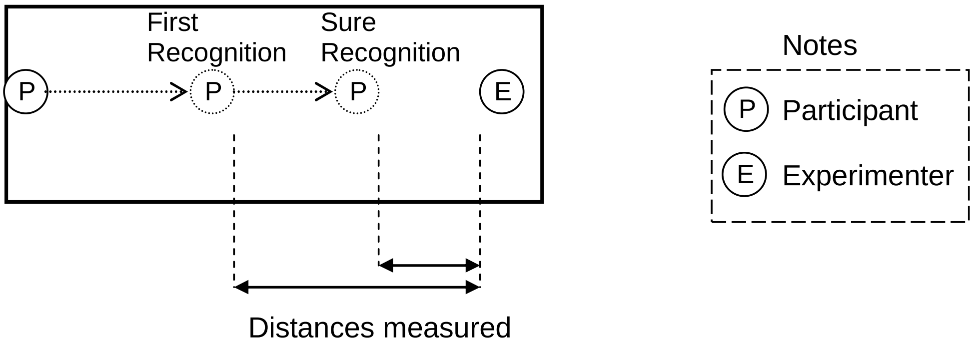


Fig.6 Facial recognition measurement (ground plan)

<u>Minimum comfortable distance measurement</u>

The minimum interpersonal distance necessary for a participant to be comfortable in terms of closeness to another pedestrian was also measured. In this measurement, each participant was asked to stand still at one end of the experiment site, and an experimenter walked toward the participant from the other end. The participant was asked to say "stop" when he/she became uncomfortable because of the close distance between the participant and the experimenter (See Fig.7). After the experimenter was asked to stop, the distance between the participant and the experimenter was measured. This procedure was repeated under the five lighting levels.

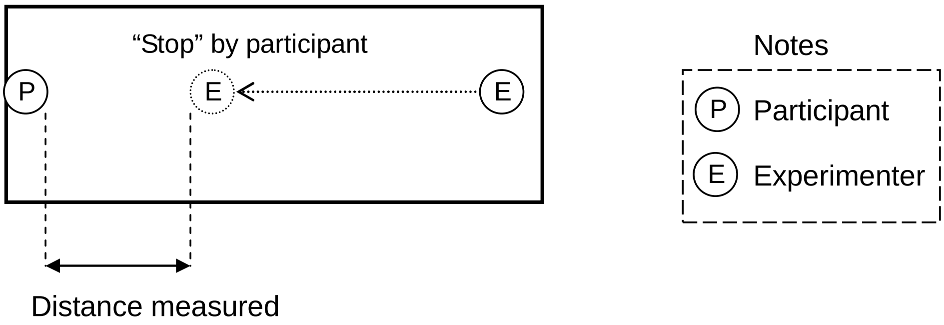


Fig.7 Minimum comfortable distance measurement (ground plan)

<u>Results</u>

The mean values of the participants for each measurement are shown in Fig.8. Also, results of a Paired T-test between the results under bright conditions (627 lux) and those in dimmed conditions are shown in Table.3.

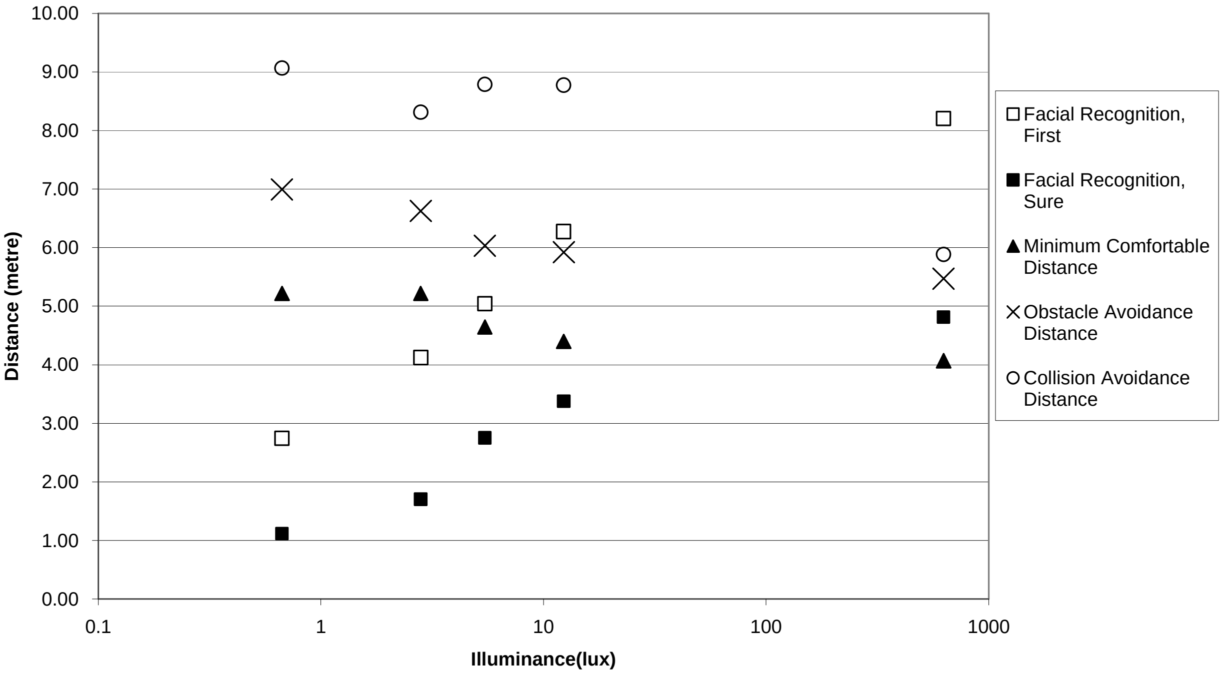


Fig.8 Results of each experiment (mean value)

Table 3. Results of paired-T test for differences between distances measured under bright conditions (627 lux) and those in dimmed conditions

	0.67 to 627(lux)	2.8 to 627(lux)	5.5 to 627(lux)	12.3 to 627(lux)
Collision avoidance distances	Not Significant	$p<0.05$	Not Significant	$p<0.05$
Obstacle avoidance distances	$p<0.05$	$p<0.01$	Not Significant	Not Significant
Minimum comfort distances	$p<0.05$	$p<0.01$	$p<0.05$	Not Significant

From these results, *collision avoidance distances* seem to be almost constant regardless of the lighting levels. *Obstacle avoidance distances* also look constant, but there is a significant difference between a distance for 627 lux and a distance for 2.8 lux, and between a distance for 627 lux and a distance for 0.6 lux. This is also the case for the *minimum comfortable distance*, which did not show a large variation in regard to the lighting levels, but which presented a significant difference between the distance for 627 lux and the distance of 2.8 lux, and between the distance for 627 lux and the distance for 0.6 lux. On the other hand, *facial recognition distances* (both *first recognition* and *sure recognition*) suggested a proportionate relationship to the lighting levels.

It should be noted that the *collision avoidance distances* were around 8.0 to 9.0 m; *obstacle avoidance distances* around 5.5 to 7.0 m; *minimum comfortable distances* around 4.0 to 5.2 m. Around 5 lux was the intersection point between *minimum comfortable distances*, which slightly increased as the lighting level decreased, and *first recognition distances*, which decreased as the lighting level decreased.

Discussion

This experiment examined how behaviour of pedestrians changes according to lighting levels. The experiment was exploratory and only a few participants were involved, but we obtained some interesting findings.

We hypothesised a large alteration of pedestrian behaviour according to lighting levels, viz a larger avoidance manoeuvre in the darker conditions. Yet, the types of pedestrian behaviour we examined did not show a substantial difference between the lighting levels tested. Only *facial recognition distances* displayed a proportionate relationship. Considering that, as studies on personal space suggested (which we saw in the "relevant research" section), the size of personal space changes according to the illuminance, one possible reason why the results of our experiment did not show such alteration can be that there is a threshold for illuminance above which the size of personal space does not change, and the illuminance levels tested in our experiment are all above this threshold. Because the size of the personal space does not change, collision avoidance behaviour did not change.

Studies on emergency lighting have shown that below illuminance of 0.2 lux or less, time taken to evacuate in a building rapidly increases (Boyce (1985), Simmons (1975)). These studies infer that above 0.2 lux people may gather visual information necessary to walk to a destination as fast as in the normal illuminance level.

In our experiment, *first facial recognition distances* intersected *minimum comfort distances* at around 5 lux. Also, at 5 lux or a lower level, *minimum comfort distances* and *obstacle avoidance distances* differed from the equivalent values under bright conditions. 5 lux is a reasonable value insofar as perception of individual pedestrians to another pedestrian is considered.

One of the interesting findings of our study is that pedestrians started avoiding another pedestrian at a distance of around 8 m regardless of the lighting levels. This 8 m is longer than facial recognition distances, which means that pedestrians started avoidance manoeuvres in relation to other pedestrians without facial recognition. On the other hand, collision avoidance distances were larger than obstacle avoidance distances, which means that the distance of 8m is not caused only by the physical ability to manoeuvre. In short, pedestrians can become conscious about another pedestrian and perform avoidance manoeuvre before they can recognise the other person's identity.

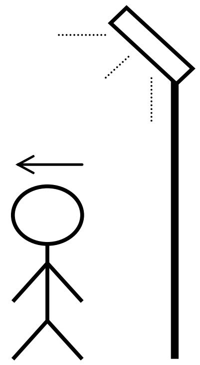
Moreover, our results showed that *collision avoidance distances* (avoidance of two pedestrians in relation to each other) were generally larger than *obstacle avoidance distances* (avoidance of a pedestrian against a stationary obstacle). *Minimum comfort distances* (a stationary person against an approaching person) were larger than the minimum comfort distances of existing personal space studies (a stationary person to a stationary person), which is around 1.2 m (e.g. Results under dimmed conditions by Adams and Zuckerman (1991)). One possible explanation for these results is that if a person (either approaching and/or approached) walks, the comfortable distance to a person or an object becomes larger. This suggests that the perception of pedestrians in motion in terms of comfort is different from that of stationary people. Also, people's perception to moving objects (including pedestrians) in terms of comfort can be larger than that to stationary objects.

So, how much illuminance is necessary for pedestrians? This can depend on what task is regarded as the criterion for lighting for pedestrians. If facial recognition at an interpersonal distance of 4 m is the criterion, as suggested by Bommel and Caminada, 5 lux may be enough. However, if provision of enough illuminance for pedestrians to recognise another pedestrian’s face when they wish to start their collision avoidance manoeuvre at an interpersonal distance of 8 m is required, more illuminance is necessary. As we assume that pedestrians are not stationary and for pedestrians more space may be necessary than stationary people in order to feel comfortable, this 8m distance may be adequate. On the other hand, if the criterion is rather visual orientation (and facial recognition is not regarded as important), lower illuminance than those suggested by current standards may be enough. Moreover, as crime reduction studies have indicated, if the criterion is facial recognition in relation to an unknown or unspecified person, such as a resident or other pedestrian, more illuminance may be required.

There are some issues to be investigated in further research in the series of experiments to be undertaken. In the collision avoidance experiment, it was observed a few times that some participants started collision avoidance soon after they started walking. Another experiment with a larger experiment field might show a different result. Also, in this limited pilot experiment, the issue of contrast was not explored – the difference between the illuminance level at one point of the surface compared with that at another. This could have a number of effects which might alter the tentative conclusions above. For example, if illuminance is not evenly distributed, is it better to reduce contrast (e.g. to reduce the variation of lighting level over the surface), in which case better results might be achieved by reducing rather than increasing the available lighting level.

Conclusion

Today’s lighting standards for pedestrians are based on the illuminance required for facial recognition at a distance of 4 m. However, in order to create safe and comfortable street environments, it may be necessary to understand better what tasks or requirements are important for pedestrians. It is recommended that, on each street, such required tasks be investigated and then required lighting levels to satisfy the tasks be considered. Tasks or requirements can be divided into categories, such as “a person level” or “community level”. Appropriate lighting levels should be considered for each task or requirement (See Fig.9). As our experiment result on facial recognition measurements showed, more lighting offers more facial recognition. Based on such research, we can identify how much lighting is necessary for pedestrians, or appropriate lighting level.



Tasks/Requirements of pedestrians

Personal level

- To notice an approaching person
- To recognise a face
- To identify an object
- …

Community level

- Visibility of pedestrians to residents and other pedestrians
- Visibility of street objects
- Visibility of houses

Fig.9 Examples of tasks or requirements of pedestrians

Because of recent developments in lighting technology, increase of lighting levels does not necessarily mean a significant rise of energy consumption. There has been development not only of energy efficient lamps, but also of efficient control systems. For example, the lighting system in Northmore, UK, which is a “Home Zone”, can alter lighting levels by time. At the midnight the lighting system there changes its output level, so that it ensures, without a significant rise of energy consumption, brighter environments when pedestrians are more likely to use streets. By using such technology, we can create more pedestrian-friendly environments at nighttime with a low cost.

This paper has explored a basis of today’s lighting standards. Current lighting standards seem reasonable inasmuch as perception and behaviour of pedestrians to another pedestrian is considered. However, if other aspects are considered, such as visibility for residents or other pedestrians, which is important for crime prevention, the levels required by current standards may be inadequate. What seems useful is to reconsider tasks or requirements in residential streets, and then to decide lighting levels to enable such tasks or requirements. Such tasks or requirements vary according to the characteristics of each street, and there could be some streets where a reduced lighting level would be enough if the lighting level of the street were to enable the tasks of the streets to proceed satisfactorily. Laboratory research following from this pilot exercise will enable these issues to be explored in more detail, under controlled conditions, so that a better understanding can be obtained and better, safer pedestrian space can be designed.

Acknowledgement

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