Does pedestrian useful visual field change at night?

Navaz Davoodian
Peter Raynham
Institute for Environmental Design and Engineering
University College London
London, UK
n.davoodian@ucl.ac.uk
p.raynham@ucl.ac.uk

***Abstract*— This paper reports an investigation into the shape and size of the useful visual field over which pedestrian visual gaze tends to fall during day and night and discusses the factors affecting useful visual field and the function of peripheral vision. A previous study by authors explored what people look at at night in the streets employing an eye tracking methodology. This study is secondary analysis of the data captured by the previous study. The study shows that street lighting affects and reduces useful visual field of pedestrians and provides guidelines to more effective distribution of light at night based on the optimum pedestrian useful field of view. Our finding emphasises the importance of illuminance on vertical surfaces and hence the for it to be considered when designing light for our streets.**

***Index Terms*—Pedestrian Lighting, Eye-tracking, Useful visual field, Road lighting**

I. Introduction

This paper reports the results of a study into the shape and size of the useful visual field over which pedestrian visual gaze tends to fall during day and night. The useful visual field in human vision corresponds to the surface around the point of fixation inside which information can be perceived and processed during a visual task[1]. The following discuss the factors affecting useful visual field and the function of peripheral vision.

A. *Useful visual field (UVF):*

UVF is the visual area from which information can be extracted without eye or head movements at a brief glance[2]. The size of the useful visual field is not fixed and is generally smaller than the visual field. It can be affected by several factors including peripheral target conspicuity [3]. The size of the useful visual field is critical for the analysis of the environment and depends on the quantity and quality of visual information[4]. The UVF decreases when the quantity of relevant information to be processed in visual field is large[1]. Central and peripheral task complexity, and priority of the central task or the peripheral task can reduce the useful visual field[5-14]. Increased cognitive work load leads to changes in visual scanning patterns and tunnel vision[10]. A tunnel vision phenomenon refers to a situation where the increasing load of the foveal task significantly deteriorates performance on the peripheral task[15]. Its size decreases when the amount of information in the visual field is large[4]. In the case of pedestrians, it is likely when the road scene is complex with numerous vehicles, pedestrians, cyclists, trees and obstacles. Any deterioration of the useful visual field has major consequences for many everyday activities[6].

B. *Peripheral vision and UVF:*

Peripheral vision comprises most of the visual field and the collaboration of central and peripheral vision plays an important role in the total performance of human vision[15]. Central vision includes fovea, parafovea and perifovea compromising 18º 20' visual angle (Image 1)[16]. After a potentially informative or visually salient object is located by the peripheral region, the following saccade will be directed to this object for more detailed examination by foveal vision. This is a general principle of visual search and scanning behavior.[17]
The central field of vision has the function of recognition and is more concerned with tasks such as the resolution of fine detail, reading, color perception, or object motion. The peripheral vision plays a dominant role in spatial orientation in the visual system[18]. While reduction of illumination reduces contrast sensitivity and recognition tasks such as reading are

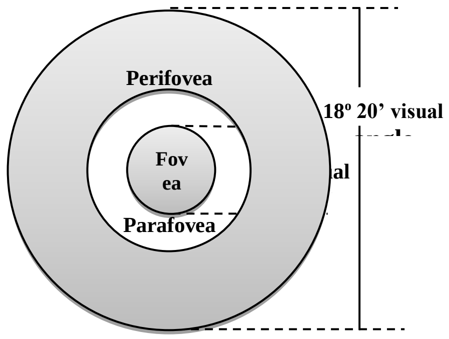

Image 1: Schematic diagram of the macula lutea of the retina, showing perifovea, parafovea, fovea, and clinical macula

impossible under low illumination levels, spatial orientation can be carried out without difficulty under low lighting level[18]. Central field recognition and peripheral field/spatial orientation are also different in the fact that people are typically aware of recognition tasks while spatial orientation is carried out reflexively or with minimal awareness. It can be easily observed in the ability of most individuals to read while walking[18].

Gaze behavior analysis has been used to investigate UVF[3, 19] by examining where car drivers look by capturing the majority of the drivers' eye movements[20]. A previous study by authors explored what people look at at night in the streets employing an eye tracking methodology. That study concluded that not only visual tasks but also reassurance can affect gaze behavior of pedestrians [21, 22]. In their study they showed that when pedestrians are more reassured they spend more time looking at the pavement and when they are less reassured they spend less time on the pavement and more time collecting information from their surroundings. This study is secondary analysis of the data captured by the previous study[20]. In the experiment participants were asked to walk along a residential street following a schematic map to find their way while their eye movements were captured using an eye tracker.

II. METHOD:

The eye tracking data was collected from two groups of participants walking in a residential area of London during day and night. Pedestrians' eye movements were recorded using a head-mounted eye tracking system. This apparatus has two cameras, one recording the field of view and one following the eye movements of pedestrians. Before each trial the eye tracking system was calibrated by instructing fixation on five distinct points arranged within the visual field (for a fully detailed methodology detail please see [21]). To extract the fixation locations ten still images from every second of video were extracted. The co-ordinates of the point of fixation and the point at eye height on the centre of the footpath, and the angle of tilt of the notional horizon were measured (Image 2). This was a complex task as the video images were not taken in a fixed frame of reference as the subjects turned and tilted their heads as they walked along. A total of 44,528 images were analysed.

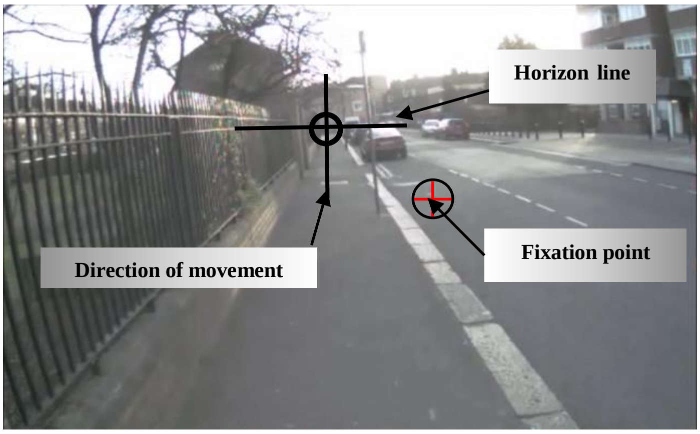

Image 2: The co-ordinates of the point of fixation and the point at eye height on the centre of the footpath, and the angle of tilt of the notional horizon were measure.

III. RESULTS:

From the measured data the angular position of the gaze direction with respect to the axis of travel along the street was measured. The visual field was divided into squares that were 1° by 1° visual angle and it was counted how many times the subjects looked in that direction and thus the percentage of time that subjects spent looking in a particular direction was measured. Figure 1 represents the gaze distribution during day and night.
Comparing the two sets of results, it is clear that during the night pedestrians tend to focus more on what is directly ahead and there is a significant drop in looking to the sides close to the horizon.
Figure 2 shows the distribution of gaze beyond 10º visual angle during day and night. Independent t-test shows gaze distribution significantly drops beyond 10º visual angle at night compare to day time, $t(7781)= 4.031$, $p=0.0001$. This results suggest that there is information available in the periphery during the day that is not accessible at night. The data has been explored to better understand the nature of the objects/areas fixated during the day in the periphery (beyond 10º visual angle). The results show that the number of fixations is significantly higher on vertical surfaces (73.79%) compared to horizontal surfaces (26.21%). It should be borne in mind that there was an asymmetry in availability of horizontal surfaces on either side of the direction of movement (see Image 3). The right side of the direction of movement had more availability of horizontal surfaces compared to the left hand side. Comparing the number of fixations on horizontal surfaces on the left hand side and right hand side of the direction of movement

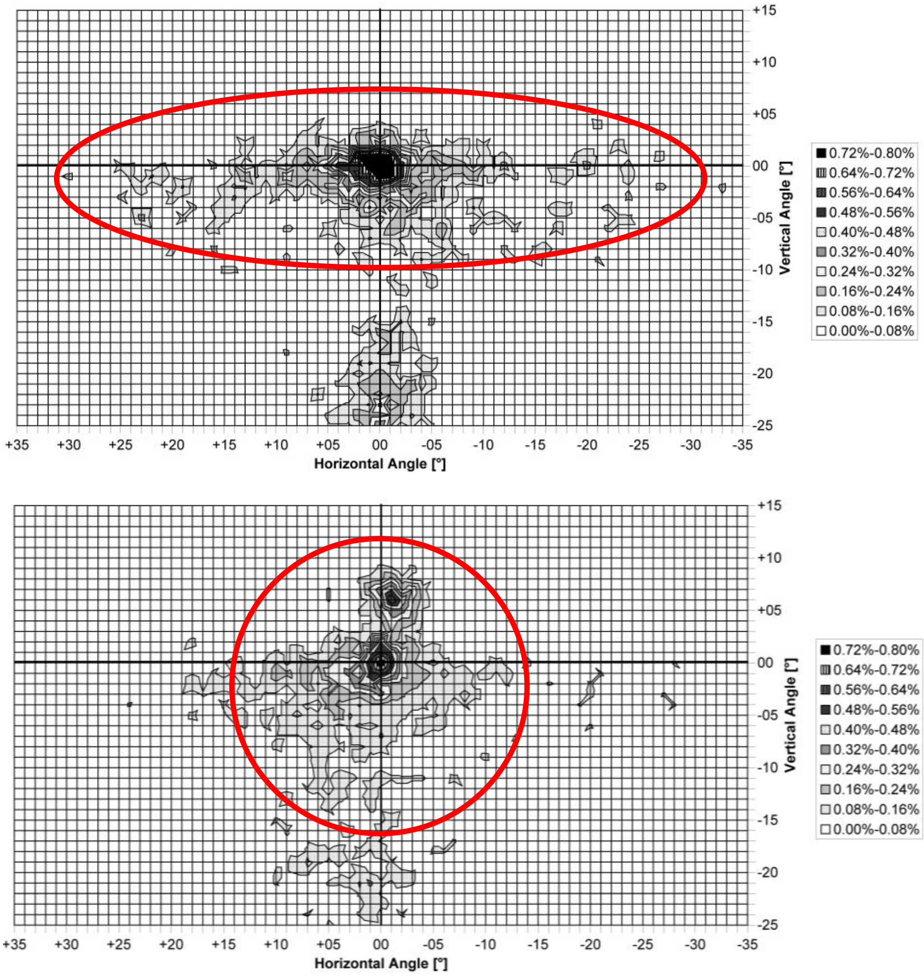

Figure 1: Above: Gaze distribution during day time. Below: Gaze distribution at night time.

shows a significant increase in the number of fixations on horizontal surfaces when there is more availability, p<0.01 (Table 1). As it is known, central vision includes fovea, para fovea, peri fovea and macula which comprises 18º 20' visual angle (Image 1). Therefore, the area beyond 10º visual angle is directly related to peripheral vision of the subjects.

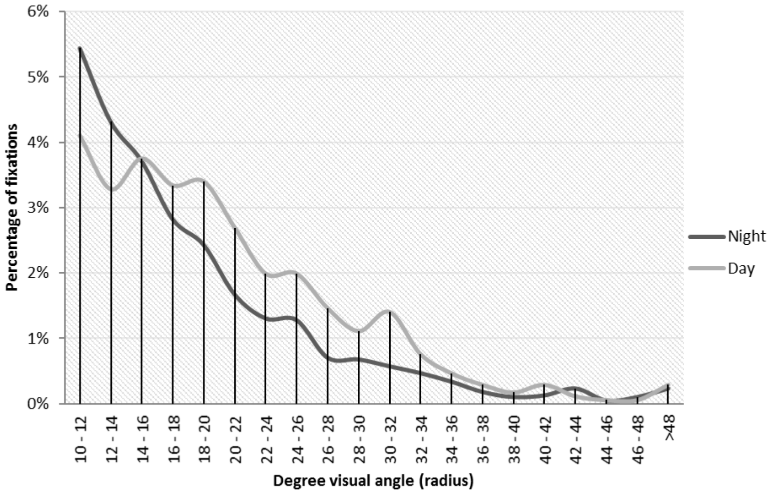

Figure 2: Comparing distribution of gazes between successive fixations beyond 10º visual angle at day and night

Additionally, a study on the objects fixated in the periphery has been carried out. However, the results do not suggest any preference to particular objects. Fixated objects vary from random objects presented in the environment to critical objects such as moving cars and bicycles.

Fixations on	Horizontal surfaces (%)	Vertical surfaces (%)
Right hand side	31.94	68.06
Left hand side	20.83	79.17

Table 1: Percentage of fixations on vertical and horizontal surfaces on both sides of the direction of movement (day time)

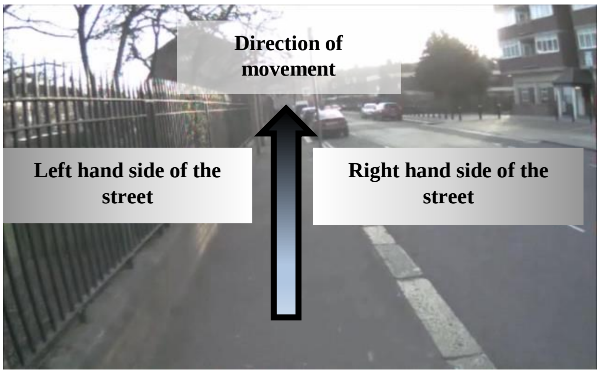

Image 3: Asymmetry in availability of horizontal surfaces on both sides of the direction of movement

IV. DISCUSSION:

The study compared pedestrian UVF during day and night. The results show that the size of UVF has decreased to central vision at night and as a result tunnel vision phenomenon[15] has occurred. Based on the discussed literature three explanations can be proposed on the loss of peripheral information at night:

- Visual saliency of objects reduces at night, so objects do not stand out and capture visual attention and consequently no gaze direction to the peripheral area (reduced UVF due to lower conspicuity of peripheral objects[3]).
- Lower illumination level at night increases the cognitive work load compare to day time and can cause tunnel vision phenomenon (increased cognitive work load leads to changes in visual scanning patterns[10]).
- A combination of both factors.

Whatever the actual explanation it is clear that the UVF at night is smaller than during the day and it would be sensible to assume that daytime conditions represent an optimum lighting condition. It may also be assumed that any change to street lighting to improve the situation should consider providing more light at the point of fixation and more light to vertical targets in the periphery. Figure 3 shows the areas for consideration, each square represents 1° visual angle.

This study of UVF also provides the basis for studying the adaptation level of pedestrians at night as the average luminance of the UVF will be a significant factor in determining the adaptation luminance. The data also suggests that it is mainly vertical surfaces have been attended in the periphery. This is the case for both left and right sides of the street even when the field of view on one side of the road is largely made up of horizontal surfaces. It may be argued that this loss of peripheral vision will affect navigation when walking. Wayfinding also seems to be affected by lighting, it is suggested that subjects tend to select different routes at night. This seems to be mostly due to changes in the perception of space and of known landmarks[23].

It is known that pedestrians' perception of space, fear of crime and wayfinding behaviour change at night mainly due to the lighting conditions in streets[23, 24]. This study aims to better understand the potential information that is lost at night compared to day time which can result in changes of perception of space, reassurance and wayfinding as well as estimating the field of view for assessing adaptation luminance.

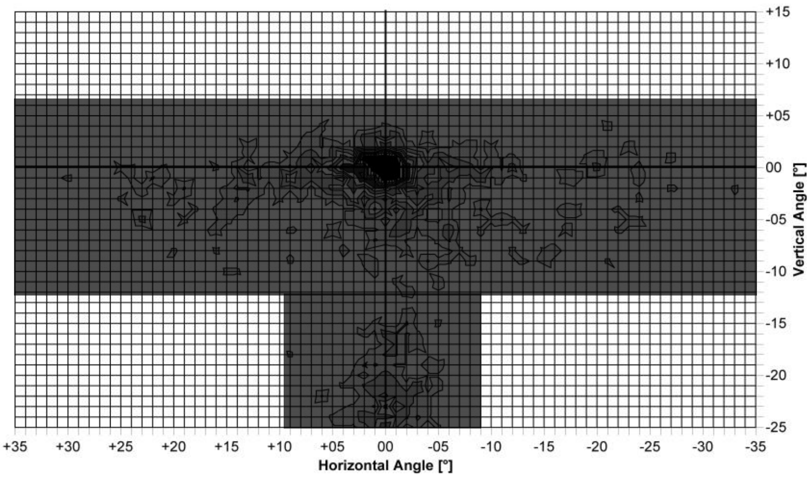

Figure 3: Above: Suggested area of attention for street lighting, each square represents 1° visual angle.

V. CONCLUSION:

The study shows that street lighting affects and reduces useful visual field of pedestrians. Our finding emphasises the importance of illuminance on vertical surfaces and hence the for it to be considered when designing light for our streets. The need for vertical illuminance on streets is starting to be recognised in lighting standards. For example the recent edition of EN 13021-2 [25] has included the option to require vertical illuminance where the road lighting is being provided to meet the needs of pedestrians and cyclists. Table 2 gives the requirements for the standard. However, the standard only suggests the application of vertical requirements when facial recognition is necessary, the findings of this study would suggest that there would be benefits from using the vertical requirements even when facial recognition was not necessary.

Class	Horizontal illuminance		Additional requirement if facial recognition is necessary	
	Ē in lxa [minimum maintained]	*Emin in lx [maintained]*	*Minimum vertical illuminance Ev,min in lx*	*Minimum semicylindrical illuminance Esc,min in lx*
P1	15.0	3.00	5.0	5.0
P2	10.0	2.00	3.0	2.0
P3	7.50	1.50	2.5	1.5
P4	5.00	1.00	1.5	1.0
P5	3.00	0.60	1.0	0.6
P6	2.00	0.40	0.6	0.2
P7	Performance not determined	Performance not determined		
a To provide for uniformity, the actual value of the maintained average illuminance shall not exceed 1.5 times the minimum Ē value indicated for the class.				

Table 2. Lighting classes for residential roads

REFERENCES

1. Mackworth, N.H., *Visual noise causes tunnel vision.* Psychonomic Science, 1965. **3**(1-12): p. 67-68.
2. Ball, K.K., V.G. Wadley, and J.D. Edwards, *Advances in technology used to assess and retrain older drivers.* Gerontechnology, 2002. **1**(4): p. 251-261.
3. Scialfa, C.T., D.M. Thomas, and K.M. Joffe, *Age differences in the useful field of view: an eye movement analysis.* Optometry & Vision Science, 1994. **71**(12): p. 736-742.
4. Rogé, J., et al., *Influence of age, speed and duration of monotonous driving task in traffic on the driver's useful visual field.* Vision research, 2004. **44**(23): p. 2737-2744.
5. Chan, A.H. and A.J. Courtney, *Foveal acuity, peripheral acuity and search performance: A review.* International Journal of Industrial Ergonomics, 1996. **18**(2): p. 113-119.
6. Rogé, J., et al., *Alteration of the useful visual field as a function of state of vigilance in simulated car driving.* Transportation research part F: traffic psychology and behaviour, 2002. **5**(3): p. 189-200.
7. Edwards, D.C. and P.A. Goolkasian, *Peripheral vision location and kinds of complex processing.* Journal of Experimental Psychology, 1974. **102**(2): p. 244.
8. Holmes, D.L., et al., *Peripheral visual processing.* Perception & Psychophysics, 1977. **22**(6): p. 571-577.
9. Ikeda, M. and T. Takeuchi, *Influence of foveal load on the functional visual field.* Perception & Psychophysics, 1975. **18**(4): p. 255-260.
10. Leibowitz, H. and S. Appelle, *The effect of a central task on luminance thresholds for peripherally presented stimuli.* Human Factors: The Journal of the Human Factors and Ergonomics Society, 1969. **11**(4): p. 387-391.
11. Noble, M. and A.F. Sanders, *Searching for traffic signals while engaged in compensatory tracking.* Human Factors: The Journal of the Human Factors and Ergonomics Society, 1980. **22**(1): p. 89-102.
12. Sanders, A.F., *Some aspects of the selective process in the functional visual field.* Ergonomics, 1970. **13**(1): p. 101-117.
13. Ward, N.J., A. Parkes, and P.R. Crone, *Effect of background scene complexity and field dependence on the legibility of head-up displays for automotive applications.* Human Factors: The Journal of the Human Factors and Ergonomics Society, 1995. **37**(4): p. 735-745.
14. Williams, L.J., *Tunnel vision or general interference? Cognitive load and attentional bias are both important.* The American journal of psychology, 1988: p. 171-191.
15. Chan, H. and A.J. Courtney, *Effects of cognitive foveal load on a peripheral single-target detection task.* Perceptual and motor skills, 1993. **77**(2): p. 515-533.
16. Riordan-Eva, P. and J. Whitcher, *Vaughan & Asbury's general ophthalmology*. 2008: Wiley Online Library.
17. Inditsky, B., H. Bodmann, and H. Fleck, *Elements of visual performance Contrast metric—visibility lobes—eye movements.* Lighting Research and Technology, 1982. **14**(4): p. 218-231.
18. Leibowitz, H. *Recent advances in our understanding of peripheral vision and some implications*. in *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*. 1986. SAGE Publications.
19. Rogé, J., et al., *Useful visual field reduction as a function of age and risk of accident in simulated car driving.* Investigative ophthalmology & visual science, 2005. **46**(5): p. 1774-1779.
20. Land, M.F., *Eye movements and the control of actions in everyday life.* Progress in retinal and eye research, 2006. **25**(3): p. 296-324.
21. Davoudian, N. and P. Raynham, *What do pedestrians look at at night?* Lighting Research and Technology, 2012. **44**(4): p. 438-448.
22. Davoudian, N. and P. Raynham, *Do pedestrians look where we lit for them in the streets?*, in *10th Biennial Conference on Environmental Psychology*. 2013: Magdeburg, Germany.
23. Del-Negro, D., *The Influence Of Lighting On Wayfinding In The Urban Environment*, in *CIE Annual Meeting*. 2015: Manchester, UK.
24. Fotios, S., J. Unwin, and S. Farrall, *Road lighting and pedestrian reassurance after dark: A review.* Lighting Research and Technology, 2014: p. 1477153514524587.
25. EN-13201-2, *Road lighting*, in *Part 2: Performance requirements*. 2015.