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CRITICAL PEDESTRIAN TASKS: USING EYE-TRACKING WITHIN A DUAL TASK PARADIGM

Fotios S.[1], Uttley J.[1], Hara N.[2]
[1] University of Sheffield, Sheffield, UK, [2] Kansai University, Osaka, JAPAN
steve.fotios@sheffield.ac.uk

Abstract

Current guidelines for road lighting illuminances on residential streets appear to have little empirical basis. Evidence is needed to determine suitable illuminance levels, and one element of this evidence involves understanding the critical visual tasks of pedestrians whilst walking after-dark. An eye-tracking study with a concurrent cognitive dual-task has been carried out in order to identify these critical visual tasks. Preliminary work showed that reaction time (RT) to an audio stimulus is impaired by visual distractions. A subsequent experiment was carried out in which participants walked a short route whilst wearing eye-tracking equipment and carrying out a RT task (responding to randomised audio stimuli by pressing a handheld button). The route included the residential areas adjacent to a university campus and was repeated in daylight and after-dark. It was hypothesised that instances of impaired RT during the route indicated the diversion of attention to some critical task or object in the environment. Analyses of the data involve: i) Using impaired RTs to identify moments of distraction; ii) Identifying objects/areas fixated at these moments of distraction; iii) Comparison of critical and non-critical fixations; iv) Fixation duration and frequency for different categories of object/area; and v) mean walking time for discrete sections of the route. Theses analyses will compare the daylight and after-dark conditions to determine any significant differences.

Keywords: Road Lighting, Eye Tracking, Dual Task, Pedestrians, Visual Attention

1 Introduction

Existing design criteria for road lighting in residential areas provide recommended horizontal illuminances for different types of highway. Recommended illuminances for residential streets in the UK range between 2 lux and 15 lux. However, there appears to be little empirical basis for these illuminances [Fotios and Goodman, 2012] and this was confirmed during a workshop at the CIE 2012 conference in Hangzhou [Fotios, 2012]. For example, British Standard BS5489-1:2003 [BSI, 2003] identified three levels of crime risk and suggests a higher light level be used when there is a higher crime risk: while a higher illuminance may increase feelings of safety [Boyce et al, 2000] there are no data to show that higher illuminance addresses higher crime and it may be that the lower illuminance is already sufficient to address risk of crime. The effects of lighting on crime, the reasons for its effects and the important characteristics of lighting, are not well understood [Boyce and Gutkowski, 1995].

Consider for example the evidence used to establish the three light classes (minimum average illuminances of 3.5, 6.0 and 10.0 lux) used in the UK prior to 2003 [BSI, 1992]. These illuminances were based on road lighting surveys by Simons et al [1987] in which observers rated their impressions of the lighting using a 9-point rating scale with end points labelled very poor (1) and very good (9). The three horizontal illuminances of BS5489-3:1992 [BSI, 1992] were established as those corresponding to ratings of good (7), adequate (5) and poor-to-adequate (4), which for good lighting (point 7 on the 9 point scale) was 10 lux. Consider that instead the results of de Boer's studies [de Boer, 1961; de Boer et al, 1959] had been used to establish these light levels. De Boer had also used a similar 9-point rating scale to gain impressions of the road lighting and these data reveal that an illuminance of 21 lux (assuming q_0=0.07) corresponds to a rating of good lighting (point 7 on the 9 point scale), approximately twice the amount of light than determined from the Simons et al study (Table 1).

Table 1 – Comparison of rating scales and illuminance ranges used in the studies by Simons et al [1987], de Boer [1961; see also de Boer et al, 1959]. The different illuminance ranges lead to different estimates of what constitutes 'good' lighting.

Study	Rating scale descriptors					Illuminance range	Illuminance for good (point 7) lighting
	1	3	5	7	9		
Simons et al	Very poor	Poor	Adequate	Good	Very good	1.0 to 12.0 lux	10 lux
de Boer	Bad	Inadequate	fair	Good	Excellent	0.9 to 71 lux	21 lux

NOTE de Boer reported road surface luminances: illuminances were calculated assuming q_0=0.07.

The reasons for these differences are stimulus range bias. When observers are asked to make judgements about a range of sensory stimuli they tend to rate the stimuli against each other rather than against a consistent reference stimulus. In the Simons et al study the average horizontal illuminances ranged from about 1.0 lux to 12.0 lux, while in the de Boer studies the road luminances ranged from approximately 0.06 cd/m^2 to 5.0 cd/m^2 which is an illuminance range of approximately 0.9 to 71 lux assuming an average luminance coefficient (q_0) of 0.07. The different ranges of light level lead to different estimates of what constitutes good lighting. If good lighting was related to a particular magnitude of light, this would have resulted in the same illuminance in both studies. This suggests that the three light classes recommended in BS5489-3:1992, and any subsequent standard which included these classes, are based on inappropriate data.

What is needed is a better empirical basis for recommended illuminances on residential roads and a requirement is thus understanding what visual tasks are important to pedestrians after-dark. This paper presents a study designed to improve our understanding of where pedestrians look whilst walking a street, with a particular emphasis on differences between after-dark and daylight conditions. This understanding will help develop a better empirical basis for residential street lighting illuminance levels. The study uses a novel dual-task approach to help identify critical times when someone's attention may be specifically focused on the task of walking along a street, through use of a response task to an audio stimulus. The visual behaviour and fixations at these critical times are captured through use of eye-tracking equipment.

Past studies using eye tracking to study pedestrian behaviour have tended to carry out trials in laboratory spaces with little or no visual distraction and with unspecified interior illumination [e.g. Hollands et al, 2002; Marigold and Patla, 2007]. The current study, and that of Davoudian and Raynham [2012], have extended this to conditions pertinent to road lighting by carrying out tests after-dark and in real streets.

2 Critical tasks

One approach to setting appropriate light levels is to identify the users' critical visual tasks, investigate how the performance of these tasks varies with lighting and hence interpret a minimum level of lighting. It has long been assumed that the primary functions requirements of lighting for pedestrians were to enhance brightness (a proxy for perceived safety), obstacle detection and the recognition of the intent and/or identity of other pedestrians. These were adopted following Caminada and van Bommel [1980]. What is not yet known is whether these tasks are indeed appropriate for characterising lighting, whether there are other essential visual tasks that need to be considered, and the relative importance of each task. New research is on-going through the EPSRC-funded MERLIN project (Sheffield University, UCL and City University) to better understand what is important for pedestrians.

Davoudian and Raynham [2012] used eye-tracking to identify the targets observed by pedestrians at after-dark. Figure 1 illustrates the eye-tracking apparatus and a sample record. Test participants wearing eye tracking apparatus were asked to walk three different residential routes, with five participants in daytime and 15 participants at night. It was found that they spent between 40% and 50% of the time looking at the footpath. Looking at other people is thought to be important to pedestrians but during this study the amount of time fixated on other people was very small, and that may be because there were few other people to look at during these trials.

Figure 1 – Eye-tracking apparatus and an example of the video record – the cross (amplified for this image) indicates the point of visual fixation

What these results recorded is where the test participants were looking: what it did not do is identify whether these observation points were of importance. Walking along a street is not a cognitively taxing task and it is unlikely that all of a pedestrian's fixations relate to this task. Furthermore, the object or area that a person fixates does not always reflect where their attention is focused: it is possible to attend to areas in our peripheral vision [Yantis, 1998] as well as to things unrelated to the visual environment.

This article presents a follow-up study carried out to better identify the critical objects of visual attention and this was done using eye-tracking within a dual-task paradigm.

3 The Dual Task

The dual task is a simple cognitive task designed to occupy a part of the test participants' cognitive processing ability whilst walking; it could be simple arithmetic or spelling but the current study used reaction to an audible stimulus. Interpretation assumes that delayed reaction to the audio stimulus indicates significant pre-occupation with the task of walking. and in conjunction with the eye-tracking video will identify instances of attention to critical tasks associated with walking.

A pilot study was carried out to confirm that visual distractions result in a delayed reaction time to an auditory stimulus. A simple programme was designed using the DirectRT software. Nine participants were asked to respond as quickly as possible to auditory 'beep' stimuli by pressing a button on the computer mouse, whilst watching a computer screen. The intervals between the auditory stimuli were either 1s, 1.5s, 2s, 2.5s or 3s, and these were used in a random order to ensure they could not be predicted. Ten auditory stimuli were presented whilst the screen was blank. A series of visually distracting images were then presented on the screen, with the auditory stimuli continuing concurrently. Twenty 'beep' stimuli were presented during this stage. Finally, the screen returned to being blank, with ten further auditory stimuli being presented. Reaction times to the auditory stimuli during the blank screen and visual distractor stages were compared (Figure 2). Reaction times during the visual distractor stage were significantly slower than during the blank screen stages (388ms vs 240ms, $t(8) = 5.77$, $p < .001$).

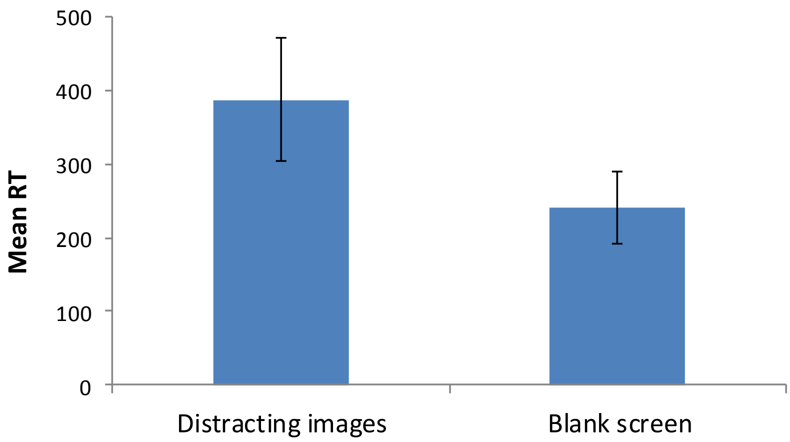

Figure 2 – Reaction time to an audio stimulus whilst observing either a blank PC screen or when the screen displayed a series of images

In addition, the consumption of cognitive capacity by the dual task is expected to result in fixations that more generally reflect the visual tasks that are important to walking down a street, compared with if no dual task was performed. This is because with less attentional resources available, participants will prioritise attending to the aspects of the visual environment that are important to the task of walking down the street, and this will be reflected in the objects and areas they fixate.

Rationale for using a dual-task is that attentional resources are finite. Introducing additional tasks that use up attentional capacity can reduce task-unrelated thoughts and the effects of visual distractors that draw our visual attention away from the task in hand. A concurrent auditory task has been shown to affect the allocation of resources to the primary visual search task [Boot et al, 2005]. Our attention may be less likely to be captured by task-irrelevant things when attentional capacity is decreased through a dual task. This finding relates to external distracters but research has also shown attentional capacity is important in determining the presence of internal distractors, e.g. task-unrelated thoughts (mind-wandering). Using up attentional capacity in task-relevant processing can reduce instances of task-unrelated thoughts [Forster and Lavie, 2009].

4 Method

The current research used a dual-task approach to determine the important visual tasks of pedestrians. Test participants walked along a defined route during which time a helmet-mounted eye-tracking apparatus recorded their visual fixation.

The route commenced from the University of Sheffield campus, it traversed adjacent residential areas and required several road crossings. The route was chosen to include sections having low and high levels of pavement obstacles and low and high levels of reassurance (perceived safety). The route length was approximately 900 m and took approximately 10 minutes to walk.

The eye-tracking system used during this study was the SMI HED iView X. This is a dark pupil tracking system, with two cameras attached to a cycle helmet worn by participants. One of the cameras faces outwards to capture the scene in front of the participants, the other (infrared) camera captures an image of the eye. Following a five-point calibration procedure the system records the participants' fixation location as an overlay on the video captured by the outwards-facing camera. The eye-tracking helmet is connected to a laptop which is carried by participants in a rucksack (see Figure 1).

The dual task used in this experiment was an auditory reaction. Whilst walking, participants heard (through a small speaker attached to the left underside of the helmet, near to the ear) a series of beeps at random, irregular intervals, between 1.0 and 3.0 s, and were asked to respond as quickly as possible each time they heard a beep by pressing a handheld button.

Each trial commenced in the lighting laboratory located in the Arts Tower building of the university campus. Firstly, test participants carried out the Ishihara test of colour perception and a Landolt ring visual acuity test to evaluate their visual status. They were then led outside to complete the walking route. Each test participant attended for two sessions, once during daylight hours and once after-dark, these being on different days, and the route direction (forward or reverse) was counter-balanced.

Immediately following the second trial, each participant was questioned about their experience during the preceding trial, and again shortly afterwards whilst reviewing the fixation-point video captured by the eye tracking equipment during their first trial. This was to gain an alternative record of the items considered to be critical.

The target number of participants for the experiment is 40. To date (February 2013) 36 participants have completed both sessions of the experiment (53% female, 39% aged under 25).

5 Analysis

At the time of writing the experiment is still on-going and therefore analyses of the data are not yet complete.

An initial analysis of the reaction times of participants who have completed the experiment has been carried out, to determine any differences between the daylight and after-dark conditions. As the route direction was different for the daylight and after-dark conditions for each participant (the route direction for their first session was reversed for their second session), route direction was first compared to determine if there were any difference in reaction time. Independent-samples t-tests showed no significant difference for route direction and this variable was therefore collapsed for subsequent analysis. Participants' reaction times during the daylight condition were compared with their reaction times during the after-dark condition using a repeated samples t-test (Figure 3). No significant difference was found (daylight mean RT = 323 ms, SD = 112 ms, after-dark mean RT = 310 ms, SD = 138 ms, $t(31) = 0.528$, $p > .05$).

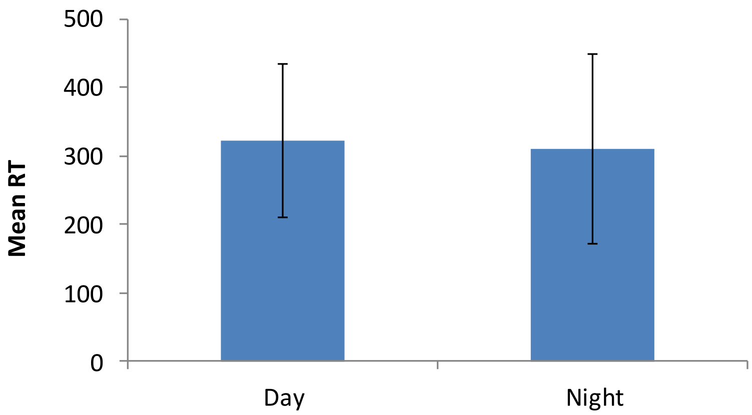

Figure 3 – Mean reaction times to an audio stimulus during daylight and after-dark walking trials.

One aim of this study was to identify the critical objects or areas fixated by a pedestrian in order to walk down a street safely. This will be done by identifying the point of fixation that coincides with a delayed response to the audio stimulus (> 2 standard deviations above the participant's mean response time). Foulsham et al [Foulsham et al, 2011] interpreted the records of an eye tracking study carried out outdoors under daylight to define six objects of interest: people, the path, and other objects, and these either near or far from the person walking. This was based on all fixations during the trial: the dual task in the current study allows us to identify which were critical, and this under daylight and after-dark conditions.

Another aim of the study is to understand whether a pedestrian's visual behaviour and the objects they look at differ under daylight and after-dark conditions. Fixations will therefore be categorised based on the type of object or area they fall on (such as pavement area, other pedestrians, obstacles etc. – defined as 'Areas Of Interest', AOIs), and the frequency and duration of fixations on these AOIs will be compared between the daylight and after-dark conditions.

A further question the study attempts to address is whether pedestrian walking time is affected by the level of natural light. This will be answered by comparing walking time to complete a particular section of the experiment route during the daylight and after-dark conditions.

Bespoke software has been written to allow comprehensive analysis of the movie captured by the eye-tracking equipment, showing the participant's view and fixation point. The software automatically locates fixations within the video and allows simple categorisation of fixation location through key presses. The software will simplify the process of registering events and objects fixated within the eye-track movie, including those that are at critical times as indicated by long reaction times.

6 Conclusion

Current guidelines for residential street lighting illuminance levels in the UK (and elsewhere) do not appear to be based on sound empirical evidence. There is a need to provide more robust evidence to inform what illuminance levels should be set. This evidence needs to address a number of questions such as what level of illuminance is required to ensure acceptable levels of reassurance amongst pedestrians, and how does illuminance levels affect pedestrians' abilities to detect obstacles that may lie in the footpath. One of the most fundamental questions however is: What visual tasks do pedestrians perform in order to walk safely along a street? The present study aims to improve our understanding of what pedestrians look at and what aspects of the street environment are visually important.

The study uses a dual-task approach in which a cognitive response-to-audio-stimulus task in conjunction with the use of eye-tracking equipment identifies critical objects and areas that are fixated by pedestrians who are walking along a street. Preliminary work showed that visual distractions do impair reaction times to an audio stimulus and this dual-task approach appears to be a useful way of highlighting important visual behaviour. It has been used in street lighting research context in the present study, but could equally be applied to other areas of visual research in natural environments.

One of the main aims of the study is to identify the critical objects observed by pedestrians in order for them to walk along a footpath safely. Once these are known we can assess how lighting affects visibility of these critical objects and what lighting conditions are optimal in order to enhance pedestrian safety. Future research will investigate this role of lighting and it is hoped that our findings will contribute to an improved evidence base on which to provide recommended street lighting illuminance levels.

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