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AN APPROACH TO SETTING ILLUMINANCES FOR SUBSIDIARY STREETS

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ABSTRACT

Current recommendations for road lighting in residential areas may be based on inappropriate evidence. A first step in providing more appropriate evidence is understanding what important visual tasks pedestrians have to perform when walking. An experiment was carried out using eye-tracking equipment to identify significant aspects of pedestrian gaze behaviour during daylight hours and after-dark. A dual-task was used in which participants had to respond to an auditory stimulus at irregular times: slow responses were used as a guide for when attention was diverted from the response task to something in the visual environment. Gaze behaviour at these times was categorised according to the significant object or area the pedestrian was looking at. Participants were more likely to look at other pedestrians or the path at critical times compared with other categories of objects, suggesting these are important visual tasks. Future research should examine how lighting affects our perception of other people and pathway characteristics, such as obstacles.

Keywords: eye tracking, dual task, pedestrians, street lighting, visual tasks

1. INTRODUCTION

Current recommended horizontal illuminance levels for road lighting in residential areas in the UK ranges between 2 and 15 lux, depending on the category of road and characteristics of usage. However, recent discussions suggest these recommended levels may be based on inappropriate evidence (Fotios & Goodman, 2012; Fotios, 2012). Therefore, new evidence is required to inform design criteria for road lighting in residential areas and ensure light levels are appropriate for users' requirements. In residential roads, pedestrians are the primary user targeted by lighting (CIE, 2010). One approach to determining appropriate light levels is understanding what visual tasks are important to pedestrians and what lighting characteristics are required to support these visual tasks. For example, previous research has suggested obstacle detection and the recognition of the intent or identity of other pedestrians are important tasks (Caminada and van Bommel, 1980). The empirical basis supporting these suggestions is not clear however, and evidence is required to identify the essential visual tasks performed by pedestrians as they walk under road lighting after dark. This paper reports a study designed to provide evidence about the important gaze behaviour of pedestrians using eye-tracking. Previous eye-tracking research (with few exceptions, such as Davoudian and Raynham, 2012) has tended to take place in laboratory settings and without reference to lighting conditions and their effect on gaze behaviour and with very safe situations (e.g. Hollands et al, 2002; Marigold & Patla, 2007). The current study uses eye-tracking in real streets, dynamic setting, during daytime and after-dark conditions.

Davoudian and Raynham (2012) used eye-tracking to identify fixations made by pedestrians during the daytime and after-dark. They found that participants spent between 40% and 50% of the time looking at the footpath. This result describes where pedestrians spent a lot of their time looking; it does not however describe whether these observation points were of importance. A major reason for this lies in the fact our attention may not always be directed towards what we are looking at or towards the task in hand. Walking along a street is not cognitively taxing and it is unlikely all of a pedestrian's fixations relate to this task. It is also likely that a pedestrian's attention is sometimes unrelated to the visual environment (e.g. when the mind wanders (Forster and Lavie, 2009)), or is directed towards something in our peripheral rather than foveal vision (Yantis, 1998). The current study used a novel dual-task approach to address this question of identifying gaze behaviour that is significant to the task of walking a street.

2. THE DUAL TASK

A simple cognitive task was used concurrently with eye-tracking to occupy some of the participants' cognitive processing ability whilst walking. The task used in this study was reaction to an auditory stimulus. Reaction times to the auditory stimulus were measured, and significantly delayed or absent responses were interpreted as indicating a diversion of attention away from the response task to something related to the task of walking. When analysed in conjunction with the eye-tracking video these delayed or absent responses (critical times) identify instances when the participants' attention is focused on important tasks associated with walking.

The premise of the dual task to identify critical visual tasks relies on visual distractions or important visual stimuli causing delayed responses to an auditory stimulus. This premise was tested during a pilot study in which subjects (n = 9) were exposed to visually distracting images on a computer screen during a response to auditory stimulus task. Reaction times to the auditory stimulus were significantly slower during the presentation of distracting images compared with no images (Fotios, Uttley and Hara, 2013). This result confirmed that a response to auditory stimuli task could be used to identify instances of visual distraction or significance.

3. METHOD

The study used a dual-task approach to identify important visual behaviour carried out by pedestrians during the day and after-dark. Test participants walked a defined route whilst wearing eye-tracking equipment and responding to an auditory stimulus. The route was divided into four sections and designed to include differing levels of pavement obstacles and reassurance (perceived safety). The route was mainly situated on the University of Sheffield campus although one section traversed an adjacent residential area. The route was approximately 900m in length and took approximately 10 minutes to walk.

The eye-tracking system used to capture gaze behaviour was the SMI HED iView X. Two cameras were mounted on a cycle helmet worn by the participant, one to capture an image of the participant's eye and one to capture the scene facing the participant. The eye-tracking helmet is connected to a laptop, carried by the participant in a rucksack. Following a five-point calibration procedure the system records the participants' gaze location as a cursor on the video captured by the outward-facing camera.

The dual task was to respond to an auditory stimulus. A small speaker was attached to the left underside of the helmet, near to the ear. This produced an audible beep at random intervals between 1 and 3 seconds. Participants were asked to respond as quickly as possible to these beeps by pressing a handheld button and reaction times to the auditory stimulus were recorded automatically.

The eye tracking and response task equipment was set up in the lighting laboratory. Participants were allowed to familiarise themselves with the response task before being taken outside for calibration of the eye-tracking equipment and then being led to the start of the route. Each participant attended two sessions on separate days, once during daylight hours (before 1700) and once after dark (1700 to 2000). The route direction for each session was counterbalanced with the route direction being reversed for one of the two sessions. At the beginning of each section the experimenter described the route to the participant and followed a short distance (~ 5 m) behind the participant. Immediately following the second session participants returned to the lighting laboratory and were questioned about their experience during the preceding trial. They were also questioned about the first trial whilst reviewing the captured eye-tracking video from this session.

Forty participants took part in the experiment, completing both daylight and after-dark sessions (53% male, 73% aged under 35). Participants had normal or corrected-to-normal vision as tested through Landolt acuity and Ishihara colour vision tests.

4. RESULTS

4.1. Variables

Three dependent variables are reported in the current paper:

1. Mean reaction time (MRT). This is the mean reaction time to the auditory stimulus for all participants. Calculation excludes 'missed' responses - occasions when participants did not press the response button following an auditory stimulus.
2. Proportion of responses classed as 'critical'. If a response to an auditory stimulus was two standard deviations above the mean reaction time, or if the auditory stimulus was missed, it was defined as being critical. The variable was calculated as the proportion of all auditory stimuli that occurred during the experiment classed as critical.
3. Proportion of critical times spent looking at different categories of object or area. Eight categories were defined to characterise the types of objects and areas participants looked at (Table 1). Fixations at critical times that could not be categorised due to little or no gaze data were excluded from analyses reported below. Each critical time was placed into one of the categories, based on a judgement made by one of the researchers. This judgement was based on viewing a one second period of the eye-tracking video before and after the critical time and determining what was the most significant object or area being looked at during that time.

Table 1 – Description of groups used to categorise significant object / area looked at during critical times

Category	Description	Category	Description
Person	Other pedestrians	**Vehicle**	Stationary or moving vehicle (including bicycles)
Path	Pathway in direction of travel	**Trip hazard**	Small object or pathway characteristic that could cause pedestrian to trip
Hidden location	Potential expected location of hidden person or object, e.g. around an obscured corner	**Large object**	Larger object in pathway that pedestrian has to navigate around, e.g. street furniture or lamp post
Goal	Target destination or waypoint towards destination	**General environment**	Areas of environment not fitting into other categories

The three dependent variables were analysed by one independent variable, the light condition (*day* versus *night*). All participants carried out one session during daylight hours and one session during hours of darkness.

4.2. Mean reaction time

Mean reaction times in the response task were calculated for both sessions carried out by participants. The overall mean reaction time across both sessions was 345 ms (s.d. = 83 ms). A paired-samples t-test was used to compare reaction times across day and night conditions. This did not suggest significant differences between the two light conditions (daylight MRT = 347 ms, after-dark MRT = 347 ms, $t(38) = -0.015$, $p > 0.05$).

4.3. Critical responses

The mean number of auditory stimuli participants were expected to respond to in each session was 275 (s.d. = 26). The number of 'critical' times during each session (*%*crit – defined as responses two standard deviations or more above the mean reaction time for each participant, or a missed response) was calculated as a proportion of the total number of responses that could have been made during that session. The mean proportion of potential responses that were critical across both sessions was 5.4% (s.d. = 1.7%). Daytime and after-dark conditions were compared. These data were not normally distributed, therefore median values are reported and non-parametric statistical tests were used. The Wilcoxon signed-rank test does not suggest significant difference between the proportions of responses that were critical during the daytime and after-dark (respective medians = 5.2% and 4.9%, $T = 18.4$, $p > 0.05$).

4.4. Critical gaze behaviour

Each critical response was placed into one of eight categories (or the Unknown category) based on an interpretation of the most significant object or area the participant was looking at, at the time of the critical response. Frequencies in each category were converted to a proportion of the total number of critical responses (excluding the unknown category) for that session. Daytime and after-dark conditions were compared to determine whether the lighting condition had an effect. As the data were not normally distributed, Wilcoxon signed-rank tests were carried out to compare the daytime and after-dark conditions for each category of object/area, with a Bonferroni correction applied to the significance threshold used (corrected threshold = 0.0063). No daytime – after-dark comparisons reached this corrected significant threshold (p-values ranged between 0.034 – 0.849). As no difference was detected between daytime and after-dark conditions, both sessions were combined to give an overall mean proportion of critical responses per category. Figure 1 presents the overall proportions for each category.

A series of one-sample Wilcoxon signed-rank tests (with Bonferroni-corrected significance threshold) were carried out to compare category proportions with a hypothesised median proportion if all categories had equal proportions (with eight categories, this hypothesised equal median proportion is 12.5%). The 'Person' and 'Path' categories showed significantly higher proportions of critical gaze behaviour compared with the hypothesised median (median proportions = 19% and 22% respectively, $p = 0.001$). The 'Vehicle', 'Trip hazard' and 'Large object' categories showed significantly lower proportions compared with the hypothesised median (median proportions = 7%, 6% and 2% respectively, $p < 0.005$).

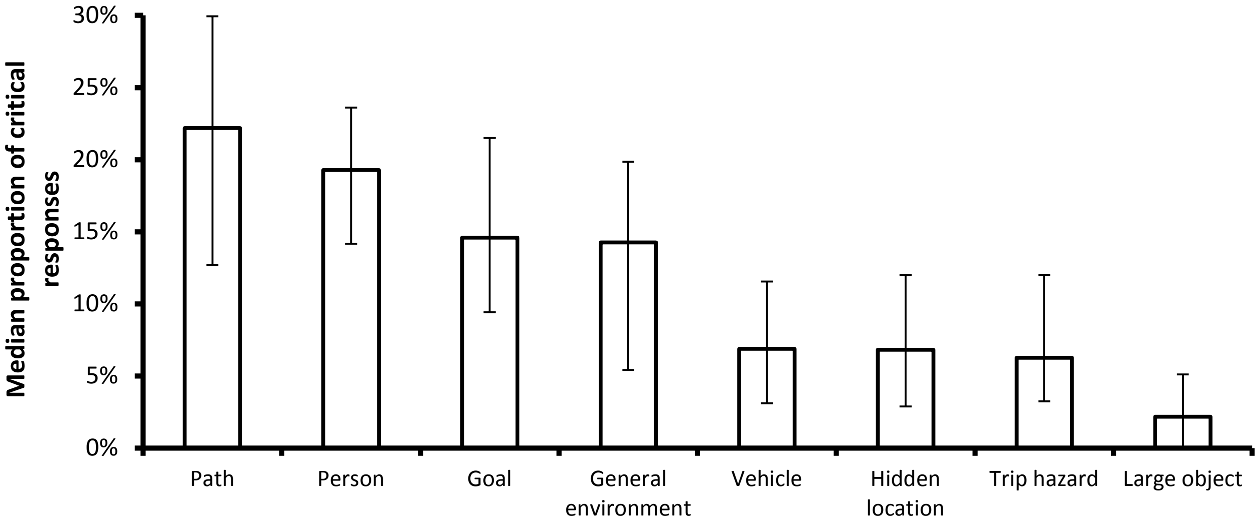

Figure 1 – Median proportions of critical responses by category of significant object/area Error bars show interquartile range. Note: these data exclude 12 test participants whose data suggested <5 gaze categories other than unknown.

5. DISCUSSION

Existing guidelines for the horizontal illuminance levels provided by street lighting on residential roads may not be based on sound empirical evidence. This paper presents initial work to improve our understanding of what the key aims of street lighting should be in order to meet pedestrian needs.

Data from participants was compared between their daytime and after-dark sessions as it was hypothesised there may be differences in reaction times and proportion of responses that were critical as a result of changes in the way attention was allocated between the response task and the task of walking. It was also hypothesised that critical gaze behaviour may vary between daytime and after-dark sessions as a result of different visual priorities. However, no differences were found between participant reaction times during the different light conditions. Similarly, the light condition appeared to have no effect on the proportion of responses made on the dual task that were 'critical'. This suggests the light condition did not affect how distracted participants were from the dual task or their overall allocations of attentional resources whilst walking. The hypothesis that in darker conditions pedestrians may direct a greater proportion of their attention towards the visual environment and increase external vigilance was not proved by this experiment. Although there may be confounding factors which affect this interpretation, such as participants potentially feeling safer and more confident than they would normally due to the presence of the experimenter, this result suggests a brighter environment does not significantly affect pedestrians' critical fixations.

The light condition also did not appear to affect how likely participants were to look at certain types of objects or areas at critical times. At critical times, people and the footpath appear to be important things people look at. Previous research has also suggested that people and the path are likely to be important visual attractors for pedestrians (e.g. Caminada and Van Bommel, 1980; Simons et al, 1987; Davoudian and Raynham, 2012).

An aim of this research is to identify the critical visual behaviour of pedestrians. Using this information it may then be possible to develop a rationale for the lighting characteristics required from street lighting. According to the eye-tracking data reported here, it appears important for pedestrians to be able to see other pedestrians and the footpath they are walking on or towards. We can then begin to identify what is required from street lighting, e.g. in terms of illuminance, spectral power distribution or other lighting characteristics, to assist in the perception of people and the footpath. For example, research is also currently underway to identify lighting requirements for the perception of faces and body posture. These results suggest a luminance on the face of 0.1 to 1.0 cd/m^2 is required if facial expressions are to be recognised at 4 m, or >1.0 cd/m^2 if facial recognition at 10 m is required (Fotios and Yang, 2013). In terms of the importance of the footpath, one reason for this may be the detection of obstacles and trip hazards, so that any necessary changes to gait or direction can be made. Previous research has suggested 0.6 or 2.0 lux may be optimal illuminance levels for street lighting to facilitate obstacle detection, depending on the approach taken to identify the optimal level (Fotios and Cheal, 2013).

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