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# LIGHTING FOR PEDESTRIANS: WHAT ARE THE CRITICAL VISUAL TASKS?

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## Abstract

Eye tracking was carried out at daytime and after-dark in an outdoor setting, using a dual-task to identify pedestrians' critical visual fixations. The results suggest that fixations determined using the dual task provide a good estimate of the important fixations by helping to ignore the less-critical fixations. Critical fixations also appear to be robust against their frequency of occurrence in a natural setting. It was concluded that the near path (<4 m) and distant people (>4 m) are critical visual fixations for pedestrians.

*Keywords*: Eye tracking, road lighting, pedestrians, visual tasks

## 1 Introduction

Recommended illuminance levels for road lighting in the UK are given in BS EN13201-2:2003 [BSI, 2003]. The target average illuminance levels for subsidiary roads (which includes residential roads) range between 2 lux and 15 lux in six classes, chosen according to environmental zone and traffic flow [BSI, 2012]. However, these illuminance levels appear to be based on inappropriate empirical and are in need of review [Fotios and Goodman, 2012]. One approach to identifying optimum illuminances is to investigate how changes in illuminance affects those tasks considered to be important for pedestrians.

There is a tendency to assume that when lighting for pedestrians the critical visual tasks are perceived safety, obstacle detection, recognition of the intent and/or identity of other road users, and these with lighting of an acceptable appearance, following the work of Caminada & van Bommel [1980]. What is not yet known is whether these tasks are indeed appropriate for setting the design characteristics of lighting, whether there are other essential visual tasks that need to be considered, and the relative importance of each task. This article presents the conclusions drawn from a study of pedestrians' visual fixations using eye-tracking carried out to explore the critical visual tasks.

## 2 Eye tracking

The eye-tracking system used in this experiment was the iView X HED made by SensoMotoric Instruments (Figure 1). Two cameras are mounted on a cycle helmet worn by the participant. One camera records the scene facing the participant, the other camera captures an image of the right eye. A calibration procedure was used to create a reliable track of the participants' gaze position. The eye-tracking helmet was connected to a laptop carried in a rucksack by the participant. The eye-tracking system provides a video output showing the gaze position as a cursor overlay on the video of the scene facing the participant. In addition a data file is created with details of the eye-tracking samples recorded by the system, including coordinates of the gaze position. This can be used to detect fixations, saccades and blinks using software provided with the system. Gaze position accuracy is reported by the manufacturer to be typically between 0.5° - 1.0°.

Participants were asked to walk a short route circumnavigating the University of Sheffield campus whilst wearing the eye-tracking equipment and carrying out a dual task by pressing response button after frequent but random auditory stimuli (see section 3). The route was approximately 900m in length and was split into four sections (Figures 2 and 3), with each section chosen to provide different characteristics, such as road crossings or uneven terrain:

A Pedestrianised area on University campus. Generally busy with a high number of people. Flat, uniform pathway surface, few obstacles and bright road lighting.

B Mainly side streets close to University hub, mixed levels of traffic volumes. Irregular pathway surface, high number of obstacles. Includes steps and a road crossing. Generally high number of people, road lighting of medium brightness.

C Short section with uniform pathway surface. Adjacent to busy road. Generally some other people present but not high volumes. Bright road lighting.

D Residential estate that participants were generally unfamiliar with (as confirmed in debrief interviews). Residential roads with low traffic volumes. Pathway surface generally good but included changing gradients. Low numbers of other people. Some areas without road lighting, other areas with dim road lighting.

**Figure 1 – SMI iView X HED mobile eye tracking system (left) and screenshot from recorded video (right). The red cursor shows current gaze location (amplified for this image).**

On attending the first trial participants completed a Landolt ring acuity test and an Ishihara colour perception test under normal office lighting conditions. They were then set up with the eye-tracking equipment, taken outside to complete the eye-tracking calibration procedure, and then taken to the start of the route. At the beginning of each route section participants were given a description of where to walk for that section and were shown a schematic map of the route. A researcher followed the participant a short distance behind (approximately 5 m) as they walked each section. The same procedure (but without the initial vision tests) was carried out for the second session. The order of the light condition (daylight or after dark) and route direction (clockwise or anti-clockwise) was counterbalanced.

Forty participants took part in the experiment (53% male; 58% in the 18-29 age group, 35% in the 30-49 age group and 7% in the 50+ age group). Participants were screened for having normal or corrected-to-normal vision using a Landolt ring acuity test and the Ishihara colour perception test. 40% of participants wore glasses or contact lenses for viewing short- or long-distance objects. All participants reported having normal or good hearing. Each participant carried out the walk twice, once during hours of daylight and once during hours of darkness. Trials during hours of daylight occurred between 08:00 and 16:00, whilst after-dark trials occurred between 17:00 and 20:00.

The aim of this experiment was to identify the items fixated by participants and for this eight categories of fixation attention were created, chosen in part following the categories used in past work (Table 1). A ninth ‘unknown’ category was also used to collate instances when the critical fixation could not be determined due to poor eye-tracking quality or if the gaze location was off screen.

**Figure 2 – Photographs of the four route sections. Clockwise from top-left: route section A, B, C and D.**


**Figure 3 – Map of route followed by test participants. Start and end of clockwise route shown: these were reversed for anti-clockwise route.**

**Table 1 – Description of groups used to categorise fixation targets**

| Object category | Description | Object category | Description |
|---|---|---|---|
| Person | *Other pedestrians* | Vehicle | *Stationary or moving vehicle, or moving bicycle* |
| Path | *Pathway in direction of travel* | Trip hazard | *Small object or pathway irregularity that could cause pedestrian to trip* |
| Latent threat | *Hazards not visible until last moment or that not materialised yet* | Large objects | *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* |

Frame-by-frame coding of visual fixations is a demanding task, which is perhaps one reason why past studies [e.g. Foulsham et al, 2011] have examined only discrete sections of their video records. Hence, this first analysis of all-fixations used data from only ten (25%) of the forty test participants and 120 s segments from three of the four route sections (A, B and D). These ten test participants were those having high eye-tracking validity (few missing fixation data) and were balanced across trial order (daytime or after dark being the first trial) and route direction. Of the ten participants selected, six were male; five were aged under 30, three were aged 30-49, and two were aged over 50 years old. Three participants wore their normal corrective lenses.

Figure 4 shows the proportions of fixations on the different categories of object for the daytime and after dark trials. Person, path and goal are the most frequently fixated objects, in both daytime and after dark trials. The differences between daytime and after-dark appear to be small other than for the path category where there appears to be a large increase in fixations after-dark than during daytime.

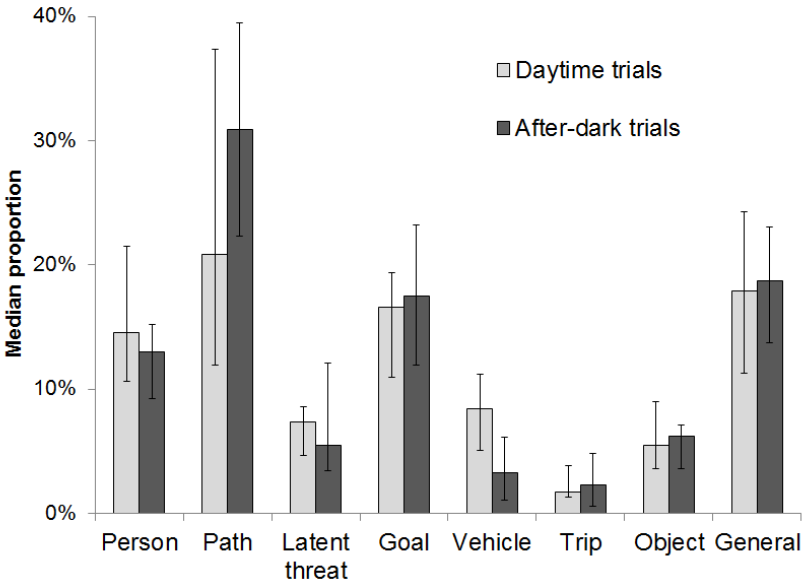


**Figure 4 – Proportions of fixations upon the eight fixation categories. These data were determined from trials carried out by 10 test participants and for 120 seconds each from three route sections. Error bars show interquartile range.**

These results are compared with those from past studies carried out in real outdoor environments in Table 2. Foulsham et al [2011] recorded visual fixations during a 5-10 minute walk to a café and found that 21% of fixation time was directed towards people, 37% towards the path, and 37% towards other objects. A second study carried out in a real environment is that of Davoudian and Raynham [2012] who found that 41-51% of fixations were directed towards the path but only 3% towards other people. There is a relatively low proportion of fixations on people, suggesting that fixation on people is not a critical task. The large differences in proportion of fixations on people in the Davoudian and Raynham study (3%) and the Foulsham et al study (21%) may arise because only few people were encountered in the Davoudian and Raynham study: these data may not be generalizable to other situations.

**Table 2 – Comparison of proportions of fixations on person, path and objects/environment categories between current study, Foulsham et al [2011] and Davoudian and Raynham [2012]**

| Category of object | | Current Results (N=10) | | Foulsham et al (2011) | Davoudian & Raynham (2012) | |
|---|---|---|---|---|---|---|
| | | Day | After dark | Day | Day | After dark |
| Person | Near | 3% | 4% | 7% | 3% | 3% |
| | Far | 16% | 8% | 14% | | |
| Path | Near | 16% | 26% | 29% | 51% | 41% |
| | Far | 10% | 8% | 8% | | |
| Objects / environment | | 55% | 55% | 37% | 46% | 56% |

NOTE: Path for the current study includes both Path and Trip hazard categories from earlier analyses. Mean rather than median proportions for current study are shown for comparability with other two studies. Near and far distance distinction is shown for comparison with Foulsham et al (see Section 4 for further details), Davoudian and Raynham did not use near and far distinction; Foulsham et al did not use after dark condition.

Counting the proportion of time for which different categories of object are fixated (all-fixations), a common approach to interpretation of eye-tracking data, suffers two limitations when searching to identify the critical tasks. First, apparent fixation on an object does not imply that fixation on the object is critical to safe walking, and similarly, it does not imply that cognitive attention was being devoted to that obstacle – the observer may have been daydreaming. 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. Second, it does not account for the frequency by which an object was encountered during the trial, this likely to be random in outdoor trials in natural settings. For example, if only one person was encountered during a trial the proportion of fixations on other people would necessarily be low, but this would be a function of the number of other people encountered.

## 3 Dual task

An attempt to better identify critical fixations was made using a dual task, a secondary cognitive task running concurrently with the task of walking, requiring that test participants responded quickly to an acoustic signal by pressing a button: delayed response to this task was used to isolate moments where cognitive attention was distracted toward a critical visual task (critical-fixations). Task instructions have been shown to focus attention allocation in a dual task setting [Kelly et al, 2010], and participants were instructed to respond to the acoustic signal as quickly as possible, so that instances of mind-wandering were reduced.

An Arduino microcontroller connected with a mini-speaker and response button was used to provide the concurrent dual task. The speaker was attached to the underside of the eye-tracking helmet, close to the left ear. The speaker emitted an audible beep at random intervals between 1 s and 3 s. The timing of each beep and each press on the response button was recorded. During trials test participants were instructed to press the button in response to every beep as quickly as possible, and were given an opportunity to practice this response prior to the start.

A delayed response to the dual task was defined as being two standard deviations greater than the participant's mean reaction time for that session. Failure to respond to an auditory stimulus was also classed as a critical time. At an instant suggested to be critical the experimenter inspected the video record to establish the object of visual fixation at that instant. This judgement was made by observing a two-second period of the eye-tracking video starting 1 s before the critical time, and the categorisation was based on what the researcher judged to be the most significant thing being observed at the time.

Figure 5 shows the proportions of fixations on the different categories of object as determined using the critical-fixations and all-fixations methods for the daytime and after-dark trials respectively, and these are for the same 10 test participants as Figure 4. In daytime and after-dark trials, critical-fixations indicate a higher proportion of fixations on people and vehicles than do all-fixations.

A conclusion drawn from the all-fixations data (Figure 4) is that "path" is the most important category of object as it has the highest proportion of fixations: observing other people appears less important. The critical-fixations approach reveals higher proportions of fixations on people and vehicles than did all-fixations, although these differences did not reach statistical significance. This increase in apparent importance reflects the increase in visual attention expected for objects of whose behaviours are less predictable than typically static items such as path, objects and goals. Jovancevic-Misic and Hayhoe [2009] found that pedestrians walking in an unpredictable way were more likely to be fixated, and fixated for a longer duration, than pedestrians who were predictable in their movements. Other research has shown an unpredictable feature of an environment produces greater fixation durations [Cinelli, Patla and Allard, 2009], and more frequent fixations [Droll and Hayhoe, 2007] than a predictable feature. Thus we suggest that the dual task provides an improved approach to identifying the critical fixations from amongst the complete set of fixations. A more complete analysis of critical fixations was therefore carried out using the larger sample size.

Of the 40 test participants recruited for this study, some had relatively high numbers of critical observations in the unknown category due to poor eye-tracking quality. Therefore participants were only included in the analysis if they had a total of at least five critical observations in categories other than unknown in both the daytime trial and after-dark trials. This criterion resulted in 12 participants being excluded. Figure 6 shows the proportion of critical observations in each category during the day and after-dark trials for the remaining 28 participants.

Figure 6 suggests that person and path are the most frequent critical fixation categories, with path more frequently fixated after-dark and people during daytime. Possible differences between day and after-dark are suggested and a series of Wilcoxon signed-rank tests were used to test the significance of these apparent differences. For the person and path categories, the Wilcoxon test suggested day and after-dark differences to be significant at levels of $p=0.034$ and $p=0.067$ respectively, hinting at a difference, a greater proportion of path fixations and a smaller proportion of person fixations after dark than during daytime. This may reflect behaviour to fixate less frequently on people after dark, but it may also reflect that fewer people were present after dark. For the other six categories the differences were not close to significance (p values of 0.143 to 0.849), suggesting a clear difference between the path and person groups and the other groups.

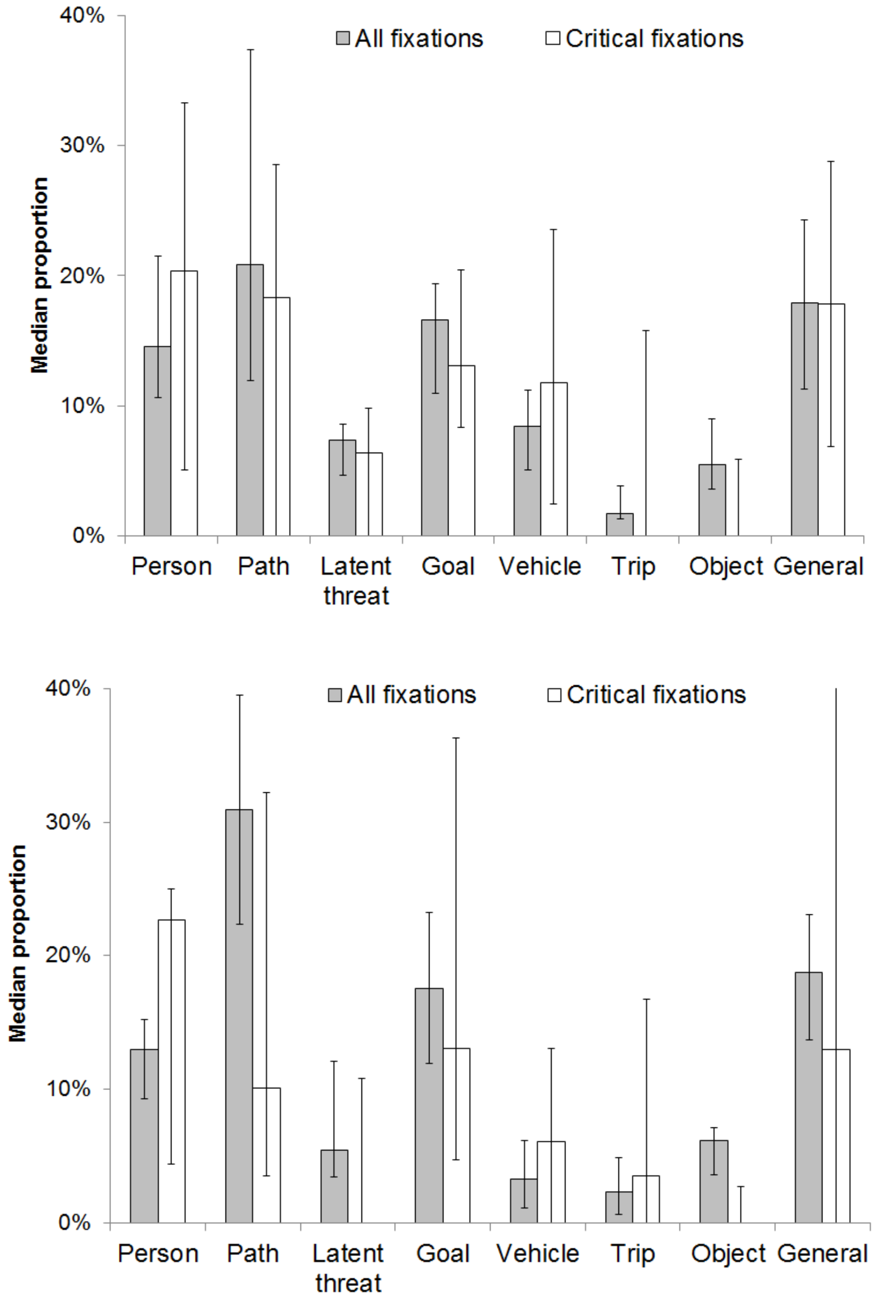


**Figure 5 – Median proportions of all-fixations and critical-fixations per category during daytime (top) and after-dark (bottom) test sessions with 10 test participants. Error bars represent interquartile range.**

## 4 Frequency of occurrence: fixation on pedestrians

A limitation of studying fixations when walking in an uncontrolled outdoor setting is that each test participant has a different experience, encountering different samples of pedestrians, vehicles and other discrete items. Hence one possible reason why Davoudian and Raynham report a smaller fixation on people (3%) than did Foulsham et al (21%) is that fewer people were encountered during their trials. An alternative approach to interpretations of eye-tracking data is to examine the probability that a pedestrian appearing in the field of view is fixated at least once. A greater probability of fixation may reflect greater importance as it increasingly demonstrates that visual information about that object is required.

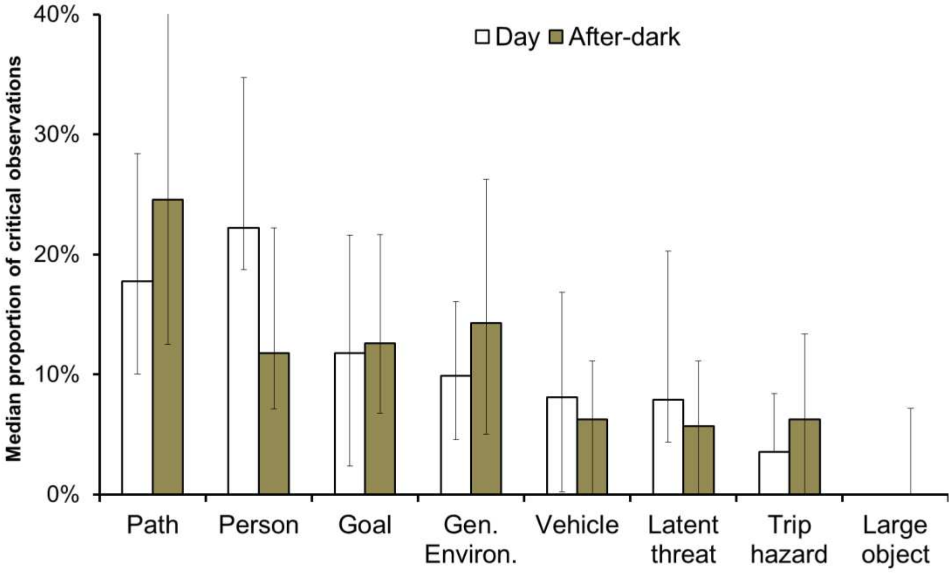


**Figure 6 – Median proportion of critical observations in each category by day and after-dark conditions. Error bars show interquartile range. Median value = 0% for Large object day and after-dark conditions. Note: data from 28 test participants**

Thus a third procedure was used to interpret the eye-tracking data: probability was determined by counting the number of pedestrians appearing in the field of view, and from these the number who were fixated at least once. One limitation of a probability approach is that only certain types of objects may be meaningfully analysed, i.e. discrete events such as people and vehicles, but not items such as pavements which are likely to be continually present in the field of view. Averaged across the ten test participants (as analysed for the all-fixations approach above) median fixation probability was 0.87 in daytime, 0.86 after dark, and 0.86 overall. These data are of a similar order to that reported by Foulsham et al [2011] (0.83).

Figure 7 shows regression of pedestrian fixation (determined using all-fixations, critical-fixations, or probability of fixation approaches) against the number of pedestrians encountered. These data show the day and after-dark trials for the ten test participants. Fixation proportion, fixation probability and number of pedestrians encountered are different kinds of measures and one way to compare these is to transform the data to z-scores [Rubin, 2013; Konar et al, 2010]. Analysis of the z-score distributions suggested that they are drawn from normally distributed populations except for the all-fixations data.

With the all-fixations data, the fixation proportion increases as the number of pedestrians encountered increases, confirming expectation that this approach suffers from stimulus bias. Spearman's test suggests this correlation to be significant ($r=0.58$, $p<0.01$). With the probability approach there is a negative relationship, in that there is a decrease in the probability of fixation as the number of people encountered increases, and the degree of correlation here is close to significant ($r=-0.40$, $p=0.08$) according to Pearson's test. This may be because with larger numbers of people it is not possible to fixate on all of them or alternatively deemed not necessary to fixate on all others. The horizontal line for critical-fixations shown in Figure 7 indicates that this approach does not have a relationship with the number of people encountered, and the Pearson's test does not suggest correlation to be significant ($r=-0.04$, $p=0.87$).

Thus the critical fixations established using the dual task leads to a more robust measure of the importance of fixating on other people as it is less affected by the number of other people encountered during trials in a natural setting.

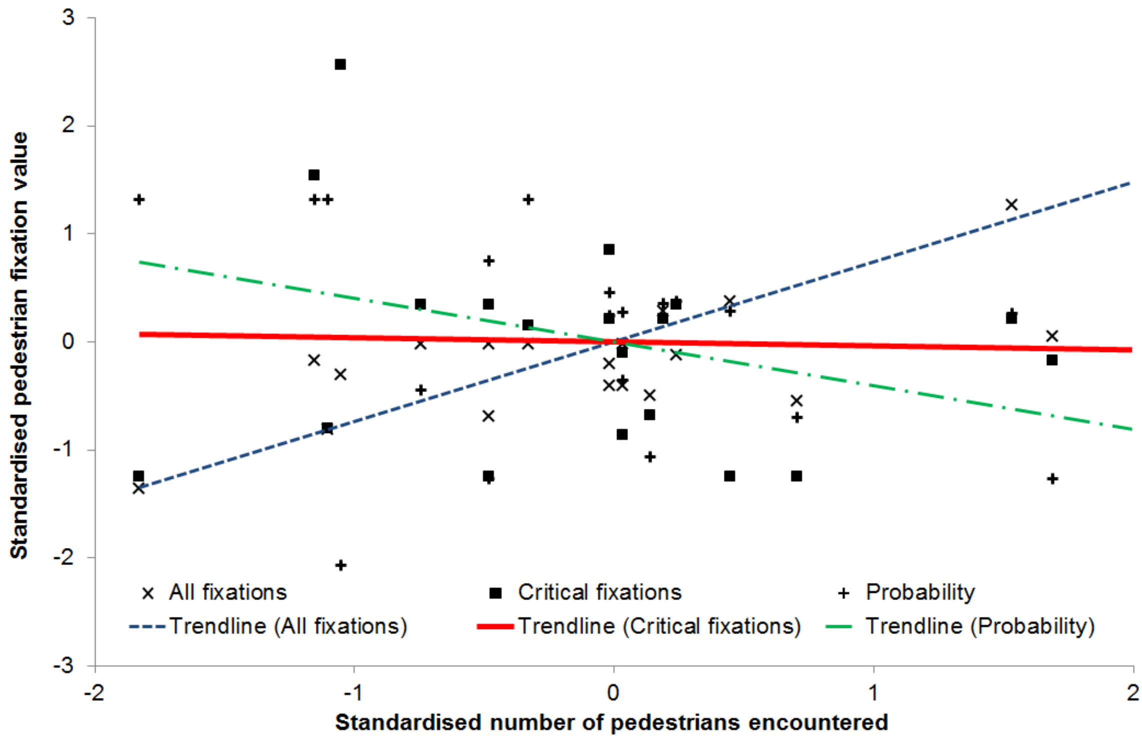


**Figure 7 – Regression of measures of pedestrian fixation against the number of pedestrians encountered. This shows data for daytime and after-dark trials**

The Path and Person categories have the highest proportions of critical observations (Figure 6). This suggests people and the path are important things for pedestrians to look at. Further analysis was carried out on these categories, examining whether critical observations were performed at a near or far distance, as has been done in past work [Foulsham et al, 2011]. Near items were those judged to be fixated within 4 m of the participant. Accurate physical measurements were not possible however, and the coder was instructed to make their own judgement, following the approach taken in previous research [Foulsham et al, 2011]. For this analysis the Trip hazard category has been included in the Path category, since trip hazards were located on the path. As with the previous analyses, the 12 participants who had less than 5 critical observations in categories other than Unknown, in either trial, were excluded. The remaining 28 participants were included.

A higher proportion of observations appear to be made at the near path compared with the far path and there is a tendency to look at other pedestrians when far away than when they are near. A Wilcoxon signed-rank test suggested the proportion of observations made at the near path was significantly higher than at the far path, when day and after-dark trials were combined (near median = 19.5%, far median = 6.3%, $T = 8$, $p < 0.001$). The proportion of observations at far people was also significantly higher than at near people (far median = 12.1%, near median = 6.6%, $T = 14.1$, $p = .04$).

## 5 Conclusion

The aim of this article is to use the results of an eye-tracking study to identify those objects of visual fixation that are critical to pedestrians. A dual task (response to an audio stimulus) was used concurrently with the eye-tracking. We conclude that this provides a better indication of which of the fixations are critical, and is less affected by the frequency of occurrence during trials in a natural setting. The data suggest that the path and people are the most important objects of visual fixation as they were more frequently fixated at critical moments than other categories of object. Further interpretation of the data suggest that these may be refined as the near path (<4m) and distant people (>4m). Further details of this work are available elsewhere [Fotios et al, in press a,b].

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