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Exploring the nature of visual fixations on other pedestrians

S Fotios PhD, **J Uttley** PhD and **S Fox** BSc
School of Architecture, University of Sheffield, Sheffield, UK

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How we look at other people may affect conclusions drawn about the effect of changes in lighting when this task needs to be done after dark. This paper reports further analysis of the distance and duration of fixation on other pedestrians, updating a previous review by considering a greater number of fixations and by examining the influence on these of other characteristics such as the relative direction of travel. This analysis provides further support for a tendency to fixate others at a distance of 15 m and for a duration of 500 ms.

1. Introduction

Pedestrians tend to visually fixate other pedestrians[1,2] and this may be done at least partially to inform the decision as to whether it is safe to approach that person or that they should be avoided.[3–6] After dark, in locations where pedestrians are expected, road lighting should aid this task.

Research has been carried out to investigate how changes in lighting affect the ability to make judgements about other pedestrians. Some studies have used a stop-distance procedure in which the test participant walks towards a target person and stops at the point when the required task (e.g. identification) can be done.[6–12] Further studies have sought judgements when targets are presented at one or more fixed distances.[13–20] The stop-distance procedure reveals the distance at which a task could be completed, but does not reveal whether that distance approximates that at which it is desirable for pedestrians after dark. Experiments seeking judgements at fixed distances may exhibit better ecological validity but only if the distances used in trials include (or bracket) that which approximates pedestrians' desired distance for evaluating other people.

Caminada and van Bommel[6] established the basis of current lighting recommendations for pedestrians and within this they adopted the distance estimates of Hall,[21] i.e. a distance of 3.7 m (12 feet) as the minimum distance at which an alert subject would be able to take evasive or defensive action if threatened, and 10 m, an ideal facial recognition distance being the transition point between the close and far phases of Hall's public zone. Fotios *et al.*[22] reviewed Hall[21] and concluded that the evidence was not sufficiently robust and furthermore that Hall had not intended its use for such a purpose. They also found disagreement with other estimates of interpersonal distance[23] and demonstrated range bias in experiments investigating comfortable interpersonal distances.[24,25]

Experiments using a stop distance procedure (along with some using fixed distances) require that the test participant continuously fixate the target person. This does not represent typical behaviour. Glances toward other people tend to be short because it is often uncomfortable to look at others for long periods[26] and because there may be no need

Address for correspondence: Steve Fotios, School of Architecture, The University of Sheffield, The Arts Tower, Western Bank, Sheffield, S10 2TN, UK.
E-mail: steve.fotios@sheffield.ac.uk

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to – information about others such as trustworthiness can be gained from exposures as short as 50 ms.[27,28]

As the light level increases (within the range of levels typical of outdoor lighting) then reaction time decreases and visual acuity increases, i.e. objects can be seen more quickly and when they are smaller or further away.[29] The accuracy of recognition judgements is affected by distance, becoming more accurate for closer targets.[30] Therefore, distance and duration matter to research of lighting for interpersonal judgements because they may affect the lighting conditions found to be optimal for this task. As a first estimate of desirable conditions, Fotios *et al.*[22] drew estimates of distance and duration from eye tracking carried out in a natural outdoor setting.[31] They found a tendency to fixate upon other people at a distance of 10.3 m and for a duration of 480 ms. When considered alongside other data these estimates were modified to a desire to fixate other people at a distance of 15 m and for a duration of 500 ms. There are two limitations to their analysis of the eye-tracking data: (1) They did not examine all of the available video records, i.e. only two of the four route sections and for the duration estimate this considered only the records for five people; and, (2) They did not record supplementary data such as the group size, gender and relative travel direction of the observed people and hence whether these factors affect the distance and duration of fixation.

This paper reports the findings of a more extensive analysis, made possible by further research funding, extending the previous study by inclusion of all sections of the available video records and by extending the range of data recorded. The key questions targeted in this paper are at what distance and for what duration do people tend to look at other pedestrians, is there a tendency to fixate either the head or body and are these affected by characteristics such as the gender and travel direction of other people?

2. Method

Further analysis was carried out of previously reported work in which mobile eye tracking was used to investigate the gaze behaviour of pedestrians walking outdoors along an urban route of approximately 900 m, in daytime and after dark.[1,31] The 40 pedestrians all followed a near-identical route, completing it in both directions on two separate occasions, resulting in the collection of 80 eye-tracking videos. A number of these sessions provided relatively poor eye-tracking signal due to loss of the pupil image, largely due to individual eye and pupil characteristics and the data being recorded in an outdoor environment with variable weather conditions (see Holmqvist *et al.*[32]). Sessions were excluded from further analysis if the proportion of valid data with acceptable point-of-regard location was below 50%. This resulted in the exclusion of 26 of the 80 videos, the remaining 54 being retained for this analysis.

Each video was coded by a primary coder to record details of every fixation to another pedestrian. Fixation of a pedestrian was defined as the gaze cursor being located on or very near to another pedestrian visible in the video, to allow for the $\pm 1^\circ$ margin of error present in the eye-tracker (as reported in the manufacturer's documentation), for at least 3 frames, or 120 ms based on the video's frame rate of 25 Hz. Table 1 lists the details that were recorded about each fixation. Distances were estimated with reference to the known size of other objects in the field of view, such as vehicles, paving slabs and street benches.

To check whether the data recorded by the primary coder were reliable, a second coder blind-recorded the same details for 288 fixations to other pedestrians. Inter-rater reliability analysis to compare the two coders was carried out using Cohen's Kappa for categorical variables and Intra-Class Correlations (ICC) for continuous variables, as described in Hallgren.[33] The resulting test values and agreement classifications are shown in Table 1.

Table 1 Details recorded about pedestrian fixations and reliability test scores between the two coders

Fixation detail	Possible values	Inter-rater reliability test and score
Fixation number (e.g. first, second, third etc. fixation of that pedestrian)	1 to n	N/A
Location	Head, Body, Unknown	Cohen's Kappa, $k=0.54$
Direction of travel	Towards, Away, Unknown	Cohen's Kappa, $k=0.82$
Gender	Male, Female, Unknown	Cohen's Kappa, $k=0.51$
Group	Solitary pedestrian, Pedestrian in group	Cohen's Kappa, $k=0.85$
Fixation duration	In frame numbers, converted to ms	Two-way mixed, agreement ICC = 0.67
Distance	Estimated distance to pedestrian, rounded to nearest metre	Two-way mixed, agreement ICC = 0.69

Classifications for describing Kappa values from Landis and Koch[34]: <0.00 = poor, 0.0–0.20 = slight, 0.21–0.40 = fair, 0.41–0.60 = moderate, 0.61–0.80 = substantial, 0.81–1.00 = almost perfect. Classifications for describing ICC values from Cicchetti[35]: <0.40 = poor, 0.40–0.59 = fair, 0.60–0.74 = good, 0.75–1.00 = excellent

Kappa values ranged between 0.51 and 0.85, which suggest 'Moderate' up to 'Almost Perfect' agreement between coders according to Landis and Koch.[34] ICC values were 0.67 and 0.69, suggesting agreement was 'good' according to thresholds set out by Cicchetti.[35] Based on the agreement classifications, agreement between the two coders on location and gender are moderate, fixation duration and distance are good and direction of travel and group are almost perfect. Overall, this suggests there was acceptable agreement between the primary and second coders, and data recorded by the primary coder have been used in all subsequent analysis.

Of the recorded measures, distance to a fixated pedestrian is one of the more subjective details estimated.[36] While recorded data showed good consistency between different coders, the accuracy to which these reflect the real distance is not revealed. A second validation step was therefore carried out. The actual distances between observer and fixated pedestrian were measured *in-situ* for 15 situations where positions of observer and fixated pedestrian could be accurately established from the eye-tracking videos and these were compared with estimated distances for those situations by the primary coder. The mean ratio of actual to estimated distances was 1.31 (s.d. = 0.38), with distances being consistently underestimated (mean estimated distance = 10.3 m, mean actual distance = 13.9 m, distances were overestimated in only 2 of the 15 situations). This is consistent with previous findings that egocentric distances are underestimated in virtual environments.[37] The mean ratio of actual to estimated distances for the 15 situations used in the validation exercise (1.31) was therefore applied to all estimated distances to account for the expected systematic underestimation: this increased the mean estimated distances of these 15 situations to 13.5 m, which is within 3% of the mean actual distance of 13.9 m.

3. Results

Fifty-four eye-tracking videos were included in the analysis, which covered 21 day sessions and 33 after-dark sessions from 37 participants. Within these videos 2496 other pedestrians were fixated, some of whom were fixated more than once, resulting in details being recorded for 5955 separate fixations. Four aspects of fixation were analysed: the number of fixations, the duration of fixations, the distance of first fixation, and whether fixation was on the head or the body. The fixation details were further analysed by the variables included in Table 1 and the gender of the observer.

Analysis of the data was carried out by calculating the mean number of fixations, mean fixation duration and mean fixation distance as recorded within each video, for each pedestrian for their night and day videos separately. These data were found to be normally distributed as assessed by inspection of normality plots, comparison of mean and median, skewness and kurtosis statistics and statistical tests against normal distribution. Parametric statistical tests have therefore been applied as appropriate.

3.1. How frequently do we fixate other pedestrians?

Observers fixated other pedestrians a mean of 2.4 times (s.d. = 0.6); Figure 1 shows the distribution of the mean number of fixations per person. This was significantly influenced by the direction of travel of the fixated pedestrian, with a repeated-measures analysis of variance (ANOVA) suggesting a significant difference between categories ($p<0.001$). A *post-hoc* Tukey HSD test suggested those pedestrians walking away from the observer attracted significantly more fixations (mean = 3.3) compared with those standing still or walking towards the observer (means = 2.1 and 2.0, respectively, $p<0.001$ in both cases). This may be because pedestrians walking away from the observer are likely to be in the field of view for a longer period of time, giving the opportunity for more fixations, or because walking away means there is no possibility of eye-contact, this giving a more comfortable situation for looking at other people.[26,38] It may also be because movement away is less familiar than movement towards and requires a longer time to make recognition-type decisions.[39] In addition to the higher mean number of fixations on people walking away from the observer, there is also a higher standard deviation: this may be an indication that there is a common motivation for fixating people approaching (considered alongside the lower mean, this might be a common desire to avoid the gaze of others) but a number of possible motivations for fixating people who are stationary or moving away.

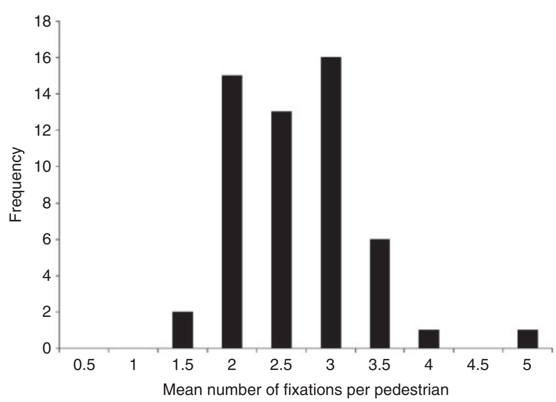

Figure 1 Mean number of fixations towards other pedestrians (N = 54). Note: bin labels on the abscissa identify the upper limit of a bin range, e.g. '2' is the range > 1.5 but ≤2.0 fixations

The mean number of fixations towards the body (mean = 1.3) tended to be slightly higher than towards the head (mean = 1.1): this difference is close to being significant ($p=0.06$). No other significant effects were found (Table 2). Regarding the gender of the fixated person, while these data did not suggest a significant difference in frequency of fixation toward males or females, the standard deviation is greater for females than for males. This might indicate a common motivation for looking at males (perhaps since considered to be the gender more likely to present a threat) but a number of possible motivations for fixating on females.

3.2. How long do we fixate other pedestrians?

The mean duration of each fixation was 475 ms (s.d. = 124 ms); the distribution of mean fixation durations is shown in Figure 2. There was no significant difference between

Table 2 Mean number and standard deviation of fixations on pedestrians by different variables

Variable		Mean number of fixations	Standard deviation	Significance
Light condition	Day	2.6	0.78	n.s.[a]
	After-dark	2.3	0.51	
Gender (observer)	Male	2.4	0.50	n.s.[a]
	Female	2.4	0.76	
Gender (fixated pedestrian)	Male	2.5	0.71	n.s.[b]
	Female	2.7	1.30	
Location on fixated pedestrian	Head	1.1	0.50	$p = 0.06$[b]
	Body	1.3	0.64	
Group	Solitary	2.4	0.72	n.s.[b]
	Group	2.5	0.99	
Direction of travel	Towards	2.0	0.53	$p < 0.001$[c]
	Stationary	2.1	1.53	
	Away	3.3	1.59	

[a]Independent t-test
[b]Dependent t-test
[c]Repeated-measures ANOVA

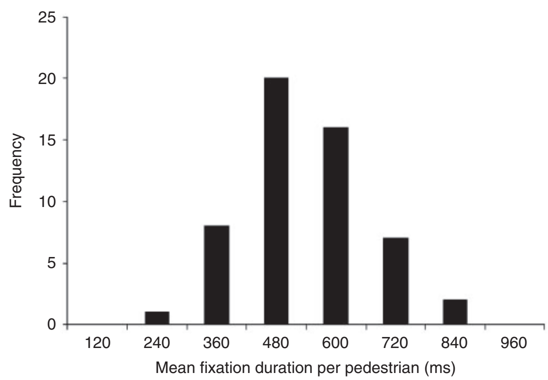

Figure 2 Mean duration of fixations towards other pedestrians ($N = 54$). Note: bin labels on the abscissa identify the upper limit of a bin range, e.g. '360' is the range >240 but ≤360 ms

the mean duration of the first fixation of a pedestrian (mean = 477 ms) and any subsequent fixations to that same pedestrian (mean = 492 ms).

Viewers tend to concentrate their fixations, including the very first fixation in a scene, on interesting and informative regions.[40] The initial fixation on a target is sufficient to allow categorisation and identification judgements[41] to allow judgements of trustworthiness[27] and provides sufficient information to correctly identify the general gist of the scene in front of the observer.[42] Given this emphasis on data extracted in the first fixation, further analyses of fixation durations (and fixation distance, see below) were therefore based on the first fixation made towards the pedestrian. The mean duration of first fixations to pedestrians was calculated for each participant and these values used in subsequent analysis. The distribution of these mean values for each participant was also approximately normal and parametric statistical tests have been used.

The first fixation tended to be of longer duration when the fixated pedestrian was on their own (mean = 515 ms) compared with in a group (mean = 417 ms, $p < 0.001$). The gender of the fixated pedestrian may have had an influence on duration of the first fixation, with a longer time spent fixating females (mean = 502 ms) compared with males (mean = 468 ms), although this difference was not significant ($p = 0.08$). No other significant effects were found (Table 3).

3.3. How far away do we fixate other pedestrians?

Analysis of the distance at which other pedestrians were fixated uses the weighted

Table 3 Mean duration and standard deviation of first fixations on pedestrians by different variables

Variable		Mean duration of first fixation (ms)	Standard deviation (ms)	Significance
Light condition	Day	472	143	n.s.[a]
	After-dark	479	132	
Gender (observer)	Male	499	135	n.s.[a]
	Female	453	135	
Gender (fixated pedestrian)	Male	468	132	Near $p=0.08$[b]
	Female	502	186	
Location on fixated pedestrian	Head	481	182	n.s.[b]
	Body	481	209	
Group	Solitary	515	179	$p<0.001$[b]
	Group	417	144	
Direction of travel	Towards	511	187	n.s.[c]
	Stationary	472	506	
	Away	451	129	

[a]Independent t-test
[b]Dependent t-test
[c]Repeated-measures ANOVA

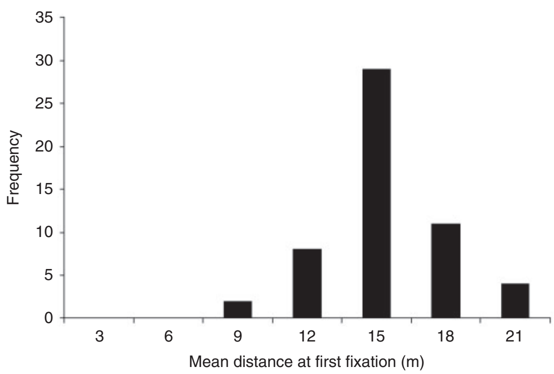

Figure 3 Distribution of mean distance of first fixations towards other pedestrians (N = 54). Note: bin labels on the abscissa identify the upper limit of a bin range, e.g. '12' is the range >9 but ≤12 m

distance estimate which accounts for the systematic underestimation of estimates by the primary coder (see Section 2 above). Figure 3 shows the distribution of mean distances at first fixation towards other pedestrians. The mean distance to pedestrians when first fixated was 14.0 m (s.d. = 2.6 m).

This distance tended to be greater during the daytime (mean = 15.0 m) compared with after-dark (mean = 13.3 m, $p=0.02$). This was found also in the previous analysis (daytime = 13.0 m, after dark = 8.9 m). The distance a pedestrian was first fixated was significantly shorter if they were on their own (mean = 13.8 m) than if they were part of a group (mean = 14.4 m, $p=0.02$). Female pedestrians tended to be fixated at a greater distance (13.7 m) than were males (mean = 13.2 m, $p=0.03$). There was a suggestion that pedestrians walking towards the observer were fixated at a slightly shorter distance (mean = 13.5 m) compared with pedestrians who were stationary or walking away from the observer (respective means = 14.3 m for both), although this difference did not reach significance (repeated-measures ANOVA, $p=0.07$). The gender of the observer and whether the first fixation was to the head or body did not have a significant effect on the distance of fixation (Table 4).

3.4. Do we fixate on different parts (head vs. body) on different fixations?

The probability of a participant looking at the body of another pedestrian rather than the head on the first fixation is 0.51 (a difference also shown in Table 2) and

Table 4 Mean distance and standard deviation of first fixations on pedestrians by different variables

Variable		Mean distance at first fixation (m)	Standard deviation (m)	Significance
Light condition	Day	15.0	2.11	$p=0.02$[a]
	After-dark	13.3	2.70	
Gender (observer)	Male	14.4	2.99	n.s.[a]
	Female	13.6	2.08	
Gender (fixated pedestrian)	Male	13.2	2.82	$p=0.03$[b]
	Female	13.7	2.81	
Location on fixated pedestrian	Head	13.4	2.94	n.s.[b]
	Body	13.3	2.98	
Group	Solitary	13.8	2.49	$p=0.02$[b]
	Group	14.4	3.24	
Direction of travel	Towards	13.5	3.03	Near, $p=0.07$[c]
	Stationary	14.3	3.56	
	Away	14.3	2.90	

[a]Independent t-test
[b]Dependent t-test
[c]Repeated-measures ANOVA

increases slightly to 0.53 for subsequent fixations. This change is not significant (dependent t-test, $p=0.36$) and does not suggest a tendency to fixate the head or body at different fixation points.

While these figures suggest similar tendencies to fixate the head or body, an area-weighted analysis would show a greater tendency to fixate the head than the body[43] as has been found by others.[44] This may be because the face contributes more information than does the body. Hahn *et al.*[30] examined recognition judgements in videos of people walking towards the camera and found that the body contributes to recognition judgements at larger distances but that the face dominates at shorter distances. Burton *et al.*[45] found that recognition was significantly affected by loss of the face in observed images but not by loss of the body or of gait.

4. Comparison with previous analysis

The original analysis[22] estimated fixation distance from 1683 discrete fixations on 1128 pedestrians and fixation duration from 177 fixations. The current analysis estimated distance and duration from 5955 fixations towards 2496 pedestrians, the higher numbers being due to an increased number of route sections, and is expected therefore to lead to more precise and accurate estimates of the nature of fixations toward other pedestrians. Table 5 compares estimates of fixation characteristics from the two studies.

The critical characteristics are the distance and duration of fixations as these parameters affect the ability to extract visual information and, therefore, the conclusions drawn about changes in lighting. The current analysis indicated fixations took place at a longer distance (mean = 14.0 m) than the previous analysis (median = 10.3 m). One reason for this is that different methods were used for estimating distance. In the first analysis[22] distance was estimated by assuming each person fixated was of an average height (1.7 m). The current approach was to estimate distance by using as a cue the size of objects in the field of view and then weighting these estimates with a correction factor to counter the distance underestimate found in the second validation process.

Table 5 Comparison of pedestrian fixation characteristics in previous[22] and current analyses

	Fotios *et al.*[22]	Current analysis	Significant affects
Number of fixations on a specific pedestrian	Mean = 1.75 (s.d. = 0.9)	Mean = 2.4 (s.d. = 0.6)	Greater number of fixations on pedestrians walking away than towards
Fixation duration	Median = 480 ms (IQR = 400–640 ms)	Mean = 475 ms (s.d. = 124 ms).	Longer duration of fixation on people when solo than when in groups
Mean fixation distance	Median = 10.3 m (IQR 8.3–12.3 m)	Mean = 14.0 m (s.d. = 2.6 m).	Greater viewing distance in day (than after dark), for people in groups Rather than solo) and for females (rather than males)

s.d.: standard deviation; IQR: Inter quartile range

This revised estimate provides further support for the proposal that 15 m is the distance at which it would be appropriate to investigate the effects of lighting on interpersonal judgements. It is a practical distance, being a shorter distance than that (23 m) at which the rate of correct facial identity recognition reduces to 25%,[46] and falls within the 'action space' zone (2–30 m) of Cutting and Vishton.[23] It is longer than the distances (4 m and 10 m) adopted by Caminada and van Bommel[6] but agrees better with opinion from design guidance texts which propose there should be an ability to have a good look at other people at distances from 12 m to 25 m,[47–49] and agrees with Townshend's finding of the preferred comfort distance after dark (15 m).[50] For 72% of the eye-tracking sessions analysed here, first fixations were made at a distance of less than 15 m.

The current analysis indicated fixations took place for a nearly identical duration (mean = 475 ms) to that found in the previous analysis (median 480 ms) and that (500 ms) which can be estimated from other work.[51] For convenience we suggest this estimate of typical fixation duration is rounded to 500 ms. The duration of fixation was affected by group size, tending to be of longer duration when fixating a pedestrian on their own compared with in a group.

5. Conclusion

The aim of this paper is to identify the typical characteristics of fixations on other pedestrians and thus to inform the design and interpretation of experiments investigating how changes in lighting affect interpersonal judgements. Fixation characteristics were established through a review of the eye-tracking records of pedestrians walking outdoors in a natural setting in daytime and after dark, extending a previous analysis[22] by analysing a much larger set of fixations. For future investigations of interpersonal judgements it is concluded that targets should simulate observation at a distance of 15 m and observation periods of 500 ms. The data do not indicate a need to discriminate between fixation on the head or body but that there may be a need to consider characteristics such as whether the fixated person is male or female and whether solo or in a group,

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