Luminance and saliency have impact on pedestrians' fixation distribution during natural walking: Evidence from mobile eye-tracker

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Luminance and saliency have impact on pedestrians' fixation distribution during natural walking: Evidence from mobile eye-tracker

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The general environmental factors that influence fixation distribution as part of pedestrian visual behaviour under natural conditions are unclear. Relative luminance and saliency are considered the parameters for predicting image-based fixation; however, they are not confirmed by evidence from the natural walking scenario. Field experiments using mobile eye-tracking glasses device were conducted on 16 participants in four commercial streets during day and night. Fixation data along with processed images extracted from eye-tracking glass video were analysed to investigate if relative luminance or saliency correlates with fixation distribution while walking. The results show that fixations within a 10° viewing angle were distributed in bright and more salient areas in the field of vision. Statistical analyses found a stronger positive correlation in saliency than in relative luminance and at night-time rather than under daylight. The correlation found between relative luminance/saliency and fixation distribution suggests that relative luminance/saliency may attract the visual attention of pedestrians. It will be beneficial for practical applications via a better visual environment, including lighting and guiding facilities for pedestrians, especially at night.

1. Introduction

The lit environment has a significant influence on human visual behaviour. Studies on visual search have demonstrated that humans sequentially allocate attention to subsets of the input while light functions as a strong stimulus.[1,2] For pedestrians, lighting is important because it aids their visual requirements, such as obstacle detection, interpersonal judgement, orientation, otherwise impaired after dark. Empirical evidence derived from previous studies on pedestrian lighting has been summarised in CIE technical report CIE 236:2019.[3]

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Visual attention must be studied to assess the effect of lighting on human vision. Under natural conditions, attending to a part of visual field is actively associated with shifts of gaze.[4] Land and Lee[5] studied the visual behaviour of drivers and this research prompted further studies. Davoudian and Raynham carried out a field investigation on the visual behaviour of pedestrians using eye tracking.[6] In recent years, studies have used eye-tracking glasses (ETGs) to investigate the visual attention of pedestrians, using these data to facilitate better lighting design. For instance, Fotios *et al*. used eye tracking to record pedestrians' visual fixations when walking outdoors in daytime and after dark

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with a concurrent dual task to establish fixations at critical moments.[7,8] Analysing critical fixations provided better understanding of which pedestrian visual tasks are important. Fotios *et al*.[9] further studied eye-tracking data to investigate the typical distance and duration of fixation of pedestrians after dark. To explain the internal causes of these practical behaviours, the influence of parameters of the whole lit environment (luminance, colour, contrast, etc.) on visual behaviour is required.

Previous studies have revealed that colour temperature and luminance have effect on the subjective impressions and visual attention in indoor environments.[10,11] Toscani *et al*. found that people tend to fixate at points with above-average luminance when they look at an object.[12] In this study, visual fixation is regarded as an ideal indicator for revealing visual information acquired by a head-mounted, a video-based eye tracker worn by subjects. The entire procedure is operated indoor with controlled environment using crafted objects. In addition, luminance contrast (LC) was found to be significantly elevating at fixation points.[13–15]

Saliency is also a possible significant factor that reflects visual attention represented by alternation of fixation. The saliency of an item is the state or quality by which it is distinct from its neighbours. Models of saliency, as bottom-up factors, often involve a concept called the saliency map.[16] Various features are computed independently (luminance, colour, orientation, etc.), filtered by differences or contrasts of these features, and then added up as saliency map. In computer vision, a saliency map is an image that shows each pixel's unique quality. These saliency maps were often referred to as bottom-up featured conspicuity maps, which represent the likelihood that a location will be attended.[17–21] In recent years, some studies have revealed the influence mechanism of saliency in outdoor walking[21]; however, further evidence from real scenes is necessary, due to the complicated outdoor lighting environment, especially at night.

Saliency map models are considered to be effective in predicting actual fixations of human observers freely viewing natural scenes under laboratory conditions. Parkhurst *et al*. used a biologically motivated computational model of bottom-up visual selective attention to examine the degree to which stimulus saliency guides the allocation of attention.[18] Four participants were presented with images of four types (home interiors, natural landscapes, buildings and city scenes and fractals) and their eye gaze data were captured by an eye tracker. It was found that the correlation between the computed stimulus saliency and fixation locations was significantly greater than that expected by chance alone, especially for the fractal images. Based on Parkhurst's results, Peters *et al*. improved the saliency model to investigate the roles of several types of non-linear interactions in visual cortex.[19] These studies were based on either images showed on screen or carried out in laboratories. However, the gaze pattern of visual search in real lighting environment may differ from that of laboratory, both in bottom-up attributes and top-down regulations.[22,23] Additional data about bottom-up visual attributes from real scene with outdoor light sources, especially natural walking, when visual attention in natural conditions is measured directly (e.g. structured eye-tracking data) are required.

Despite this research gap, the correlation between saliency and fixation has been used for predicting human gaze behaviour, especially in computer science. Einhäuser *et al*. reported that early saliency had an indirect effect on attention through recognised objects.[24] There were persistent differences between individual fixations, which were related to semantics.[25] These studies might explain the importance of top-down algorithms in predicting fixations. With further development of computer technology and significantly large database, a novel long short-term memory (LSTM)-based saliency attentive model was introduced to predict human eye fixations on natural images, which considerably performed well.[26] Different methods and effects of image-based fixation prediction were comprehensively expounded and compared by Kümmerer *et al.*, mainly based on various saliency algorithms.[27] Saliency is considered to be bottom-up parameter that can predict image-based fixation; however, it should be confirmed by further evidence from natural walking scenario in outdoor lighting environment.

Saliency is one of the factors that drive pedestrians' attention. Hayhoe and Ballard[28] introduced the use of portable eye-tracker in visual experiment and summarised the results of these experiments. They found that saliency models could explain only a small part of the fixations in natural behaviour. Saliency was further discussed in virtual–environment–walk experiments devised by Rothkopf *et al.*[29] They found that saliency model did not predict the fixations well, while the precise fixation locations on the objects were highly relative to the ongoing task. Henderson *et al.*[30] carried out an active visual search experiment to test the influence of saliency during scene viewing. Participants were asked to view photographs of real-world scenes; eye movement data were collected. Results showed that visual saliency did not account for eye movements during active search. In these studies, the experiments were either conducted indoor or the attention of subjects was heavily loaded with specific task. When a pedestrian is walking outdoors, the compulsory visual task assumes less cognitive resources, and there remains available mind that can be allocated freely. In this case, we are interested on whether saliency has an impact on pedestrian's fixation while freely walking. The influence mechanism of saliency in outdoor environment should be further investigated.

In this study, we explore the correlation between luminance or saliency and the visual fixation distribution of pedestrians during natural walking. An increase in luminance can improve the visibility of the whole field of vision, guiding pedestrians to look unnoticed objects more frequently, such as kerbs at night. Saliency attracts visual attention of pedestrians to objects to enable them to see more clearly. One example is a signboard enhanced by a high contrast reflective material at night. The text and image information contained on it are more likely to be noticed by pedestrians. This example shows how to positively use the relationship of fixation (attention) and saliency. The preliminary hypothesis is that pedestrians tend to view scenes and areas with high luminance and great saliency. Field experiments using mobile ETG were carried out in commercial streets to investigate whether the results support this hypothesis.

2. Method

2.1 Outdoor experiments

Four commercial streets were selected as experimental sites. The commercial streets contained shops, street lights, pedestrians, signs and billboards, which constituted a complex lighting environment and maintain a similar level every day in accordance with our experimental requirement. Sixteen adults (eight men and eight women) were randomly grouped into four groups, corresponding to the four experimental sites, with two women and two men in each group. All participants had normal or corrected normal visual acuity and psychological state, which were determined by a pre-test questionnaire.

For each trial, the participants (two women and two men) wore ETG (SMI ETG 2w) and walked freely for approximately 10 minutes, respectively, both at daytime (14.00–15.00) and after dark (19.00–20.00). The order in which the day and night experiments were conducted was randomised. They experiments were arranged separately as independent events, and usually only one event was performed per day. Moreover, the day and night experiments of the same subject were conducted at least one week apart to weaken their familiarity with the test environment.

Thirty-two sets of data were gained in total to enable comparison of variables such as street, time and gender. ETG and the precision of near infrared pupil measurement were recalibrated using the 3-point method before the start of each trial. Videos of the observation of participants and data of their eye movement were recorded by the ETG as raw dataset.

2.2 Image processing

In the video, the ETG record the participants' gaze behaviour and time labels throughout. A fixation event was identified using the default threshold of ETG: moving range of gaze points less than 50 pixels and duration longer than 200 ms. Similar settings were used in previous work, such as the definition of 'a conditionalised gaze duration' proposed by Carpenter and Just.[31] The video clip of a fixation event was cut into frames. The middle frame in the sequence was captured as the target image to be processed. These images were all static; motion information of objects was not included. All videos and images were processed by Python and MATLAB. The level of 8-bit greyscale (0–255) of the pixel/area was defined as relative luminance of that pixel/area. This would not distort the expected results, because the relative luminance was used, and would only be compared within the same target image.

The resolution of ETG video (also for target images) was 1280×960 in pixel and relative luminance of each pixel was obtained and saved as 'Relative Luminance Sequence'. Relative luminances of the fixation points in all target images were determined by calculating the average relative luminance of the circular area around the fixation point obtained by the ETG. The horizontal and vertical camera angles of the ETG were both 60°. We assumed the visual angle of the subjects as 2° and 10° these being the two CIE standard observers. The projection on the camera screen was a circular area with a radius of approximately 20 px or 100 px around the fixation point after calculation. An example of the fixation areas (the red and yellow circles) and instruction of visual angles in a target image is shown in Figure 1.

For each target image, the average-fixation-relative-luminance was appended into the image relative luminance sequence. The new sequence was then sorted in ascending order, and the rank of average-fixation-relative-luminance was obtained. After converting the obtained rank into percentile, the processed data point, i.e. relative luminance percentile of the fixation, corresponding to the target image was analysed.

The processing procedure for obtaining saliency data point was similar to that of luminance. However, the saliency map of target image was required prior to the derivation of the saliency sequence. A saliency map

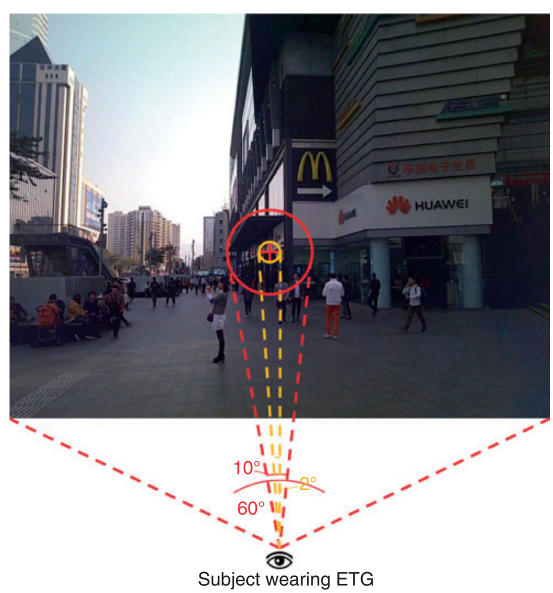

Figure 1 Example of assumed fixation areas

is an image that shows each pixel's unique quality comparing with its neighbours, which considers many factors, like colour, luminance and information richness. Harel *et al.*[32] provided an algorithm named 'Graph-Based Visual Saliency (GBVS) method' to form a saliency map from greyscale image of a digital image. In this study, all target images of all participants were first extracted in colour from the videos, and then processed into saliency map images using GBVS method (see Figure 2), which were shown in the form of greyscale pictures. In Figure 2, the influence of luminance was obvious because bright objects or areas always attract more attention in the dark. The influence of other factors is relatively weak here. Similar to luminance grey image, the pixel value of saliency map is also in 8-bit scale (0–255). For each saliency map, the average-fixation-saliency was ranked on top of the saliency sequence. After converting the obtained saliency rank into percentile, the saliency percentile of the fixation was prepared.

The operation was repeated to obtain relative luminance percentiles and saliency percentiles of all target images. For both luminance and saliency, the percentiles of all fixations from the same ETG videos of each participant were clustered and then considered, respectively, as grouped sets of data to be analysed statistically.

3. Results

3.1 Data processing

Thirty-two videos were taken, and numbers of target fixation images are presented in Table 1. Video F1D is the video was recorded in the daytime trial with female participant No. 1. Similarly, the video taken by male participant No. 2 at night-time is labelled M2N.

Images and processed data of M7D and M7N are arbitrarily presented as examples, with 10° visual angle and thus 100 px fixation radius. After calculating, two sequences of relative luminance percentiles of M7D and M7N are shown in Figure 3(a) and (b). Each element of line charts shows the position of the average-fixation-relative-luminance in the image relative luminance sequence of that target frame. An approximate distribution of relative luminance can be read from the line charts. Longitudinal coordinates denote relative luminance percentiles, and abscissae denote numbers of relative luminance percentiles in chronological order of the videos in both directions.

The dashed horizontal line in Figure 3 indicates the chance level (50%), which means that if all fixation points in target images were randomly distributed, the relative luminance percentiles should be approximately 50%. To ensure the scientific nature of this assumption, 800 target images from eight different

Figure 2 An example of original image (*left*), luminance image (*centre*) and saliency map (*right*)

Table 1 Numbers of target fixation images of all eye-tracking glass (ETG) data

	Daytime trials		Night-time trials	
Participant	Video reference	Number of fixations	Video reference	Number of fixations
F1	F1D	748	F1N	828
F2	F2D	376	F2N	553
F3	F3D	315	F3N	849
F4	F4D	306	F4N	474
F5	F5D	371	F5N	582
F6	F6D	363	F6N	536
F7	F7D	335	F7N	460
F8	F8D	539	F8N	610
M1	M1D	404	M1N	624
M2	M2D	555	M2N	534
M3	M3D	749	M3N	731
M4	M4D	596	M4N	681
M5	M5D	460	M5N	689
M6	M6D	586	M6N	614
M7	M7D	355	M7N	548
M8	M8D	367	M8N	829

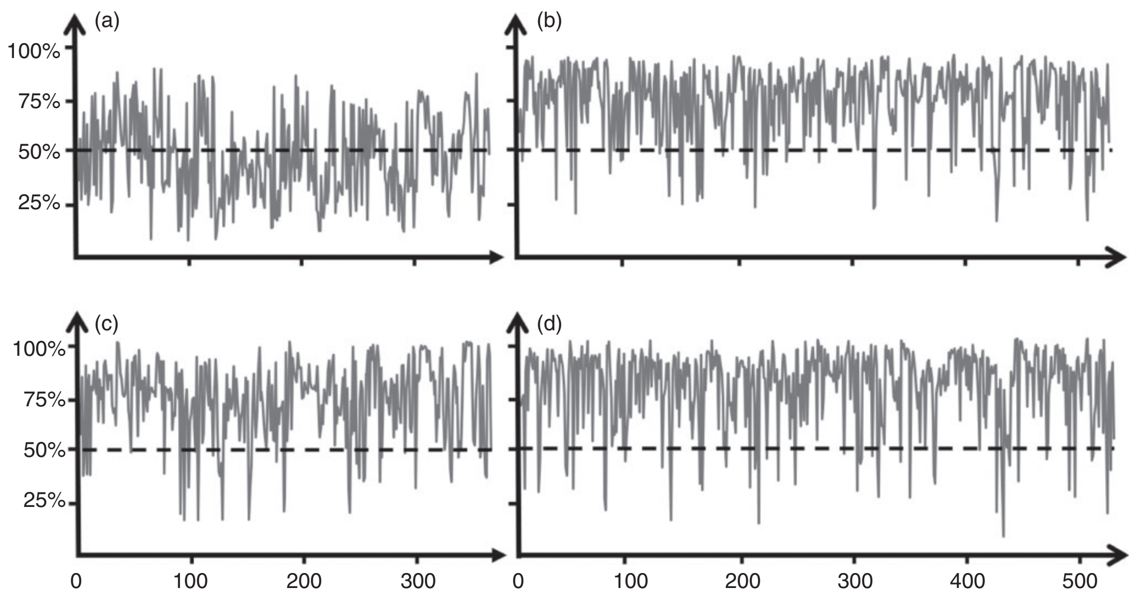

Figure 3 Relative luminance and saliency percentiles of M7D and M7N

videos were chosen for a new analysis. For each image, a random point was selected and the average luminance percentile of the circular area with 100 px radius around that point was calculated. The mean percentiles of eight videos were shown in Table 2. Percentiles were mostly in the range of 40–67%. Therefore, the assumption of 50% was reasonable.

The saliency images were processed and presented in a similar way as relative luminance as shown in Figure 3. Two sequences of saliency percentiles of M7D and M7N were shown in Figure 3(c) and (d). In these line charts, saliency percentiles of the average-fixation-relative-luminance described the distribution of saliency, showing the effect of saliency on fixation area.

Bivariate graphs combining the relative luminance percentile and saliency percentile of M7D and M7N to reveal the fixation distribution are shown in Figure 4. The horizontal and vertical coordinates represent relative luminance or saliency percentiles, respectively. Darker colour indicates denser data distribution. It can be observed that fixation distribution deviate to greater saliency during the daytime and to higher relative luminance and greater saliency during the night-time. However, these initial observations should be investigated on the overall data.

To observe the overall fixation distribution of relative luminance percentile and saliency percentile for all participants, all participants' data were summarised together in Figure 5, in daytime and night-time. It can be observed that the overall fixation distribution of relative luminance and saliency percentiles is less dispersed at night than day. The diagonal is the equal line between relative luminance and saliency. For the fixation distribution at daytime, the tendency to greater saliency is distinct, but is not obvious to higher relative luminance. The fixation distribution at night has a tendency to high end of relative luminance and great end of saliency. Compared with relative luminance, great saliency at night has a slight preponderance correlation with fixation of pedestrian. Further statistical

Table 2 Mean percentiles of eight videos for justification

Video	Mean percentile (%)
F2D	55.67
F4D	41.02
F7N	63.66
F8N	53.63
M1D	64.04
M5D	44.60
M4N	55.86
M7N	43.67

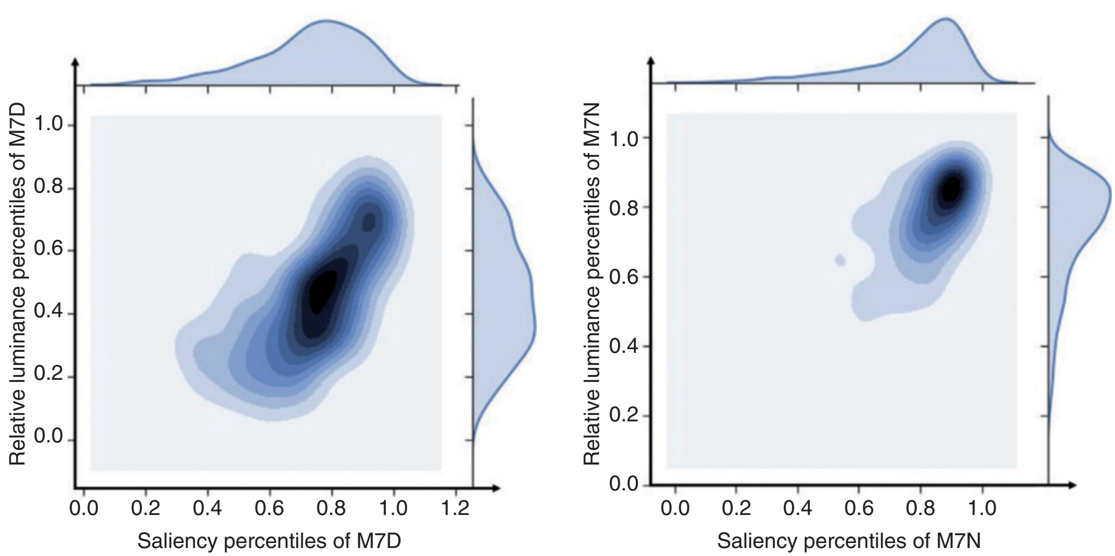

Figure 4 Joint distribution of fixation across relative luminance and saliency for M7D (*left*) and M7N (*right*)

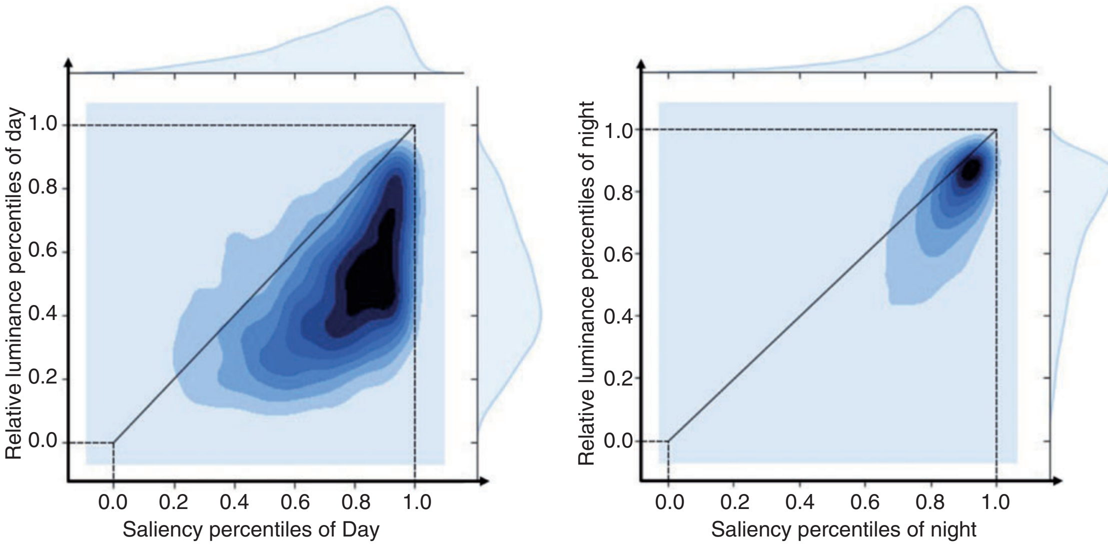

Figure 5 Overall joint distribution of fixation across relative luminance and saliency at daytime (*left*) and night-time (*right*)

analyses are required to confirm these intuitive observations.

3.2 Data analyses

For each video, sequences of both relative luminance and saliency percentile were extracted from 300 to 900 target images. The two sequences of percentile were averaged respectively to represent the average level of relative luminance and saliency that the participants tend to view when walking on the commercial streets. Mean values were used to report averages, because the data were verified to be approximately normally distributed. The mean fixation percentiles of all participants on relative luminance and saliency with 100 px fixation radius are shown in Table 3. All values of percentile (e.g. 48th) hereafter are presented in equivalent percentage form (e.g. 48%) for the purpose of explicitness. For relative luminance, the mean percentile at day and night were 47.73% and 70.00%, respectively. The mean percentile at day and night of saliency was 68.45% and 78.21%. Box plots of mean percentiles of fixations across relative luminance and saliency at day and night are presented in Figure 6. The results with a fixation radius of 20 px are shown in Table 4. Owing to the high similarity between two groups of data, we only analyse results with 100 px fixation radius. The analyses below are based on this set of data.

For each group of mean percentiles, single sample *t*-test was performed to investigate whether there was a significant difference comparing with 50 % as chance level. The results of single sample *t*-test between four groups of data and the 50% chance level are shown in Table 5. It is clear that the average percentiles of fixation distribution on saliency at day (70.00%), relative luminance and saliency at night (68.45% and 78.21%), have significant difference with 50 % chance level, whereas ‘relative luminance at day’ (47.73 %) does not.

To observe the difference between relative luminance and saliency, two paired sample *t*-tests were carried out between relative luminance and saliency for both day and

Table 3 Mean fixation percentile of each participant on relative luminance and saliency with 100 px fixation radius

Relative luminance				Saliency			
Day		Night		Day		Night	
F1D	55.86%	F1N	67.63%	F1D	75.00%	F1N	75.15%
F2D	55.41%	F2N	71.98%	F2D	68.10%	F2N	78.59%
F3D	41.97%	F3N	68.95%	F3D	61.65%	F3N	82.67%
F4D	53.43%	F4N	69.11%	F4D	68.24%	F4N	80.79%
F5D	41.37%	F5N	71.28%	F5D	55.46%	F5N	74.05%
F6D	42.87%	F6N	69.87%	F6D	60.53%	F6N	73.17%
F7D	45.23%	F7N	70.36%	F7D	79.08%	F7N	76.16%
F8D	50.81%	F8N	67.63%	F8D	71.35%	F8N	80.13%
M1D	39.41%	M1N	67.42%	M1D	69.56%	M1N	78.42%
M2D	57.40%	M2N	65.54%	M2D	82.32%	M2N	82.82%
M3D	47.37%	M3N	61.03%	M3D	84.48%	M3N	82.00%
M4D	47.81%	M4N	68.14%	M4D	73.97%	M4N	79.62%
M5D	40.77%	M5N	71.62%	M5D	57.83%	M5N	77.78%
M6D	46.80%	M6N	69.11%	M6D	76.37%	M6N	77.69%
M7D	45.65%	M7N	72.74%	M7D	72.92%	M7N	77.62%
M8D	51.54%	M8N	62.79%	M8D	63.10%	M8N	74.64%
Mean	47.73%	Mean	68.45%	Mean	70.00%	Mean	78.21%

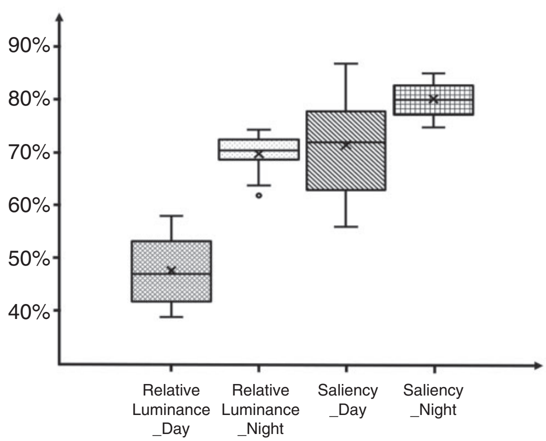

Figure 6 Box plots of mean percentiles of fixations across relative luminance and saliency at day and night

night, and the results are shown in Table 6. It turned out that saliency has a significantly stronger tendency to be correlated with fixation distributions than relative luminance at both day and night.

The difference between day and night was also observed by performing two paired sample *t*-tests, and the results are shown in Table 7. It can be observed that fixation distribution at night has a significantly stronger tendency to be correlated with both relative luminance and saliency than at day. Furthermore, while a difference between gender was observed in the data, statistical analysis did not suggest this to be significant.

4. Discussion

The results of data analyses based on field experiments using ETG on commercial streets show that the fixation distribution of pedestrians is associated with high relative luminance and great saliency. These findings indicate that pedestrians have a tendency to view bright and salient regions in the outdoor visual environment. However, it is noted that fixations for relative luminance at daytime distributed on the area that are slightly but not significantly less bright. This might be caused by the sky with relatively high relative luminance, which composed a considerable proportion in the ETG video. Therefore, it might be conjectured that the positive correlation of relative luminance and fixation

Table 4 Mean fixation percentile of each participant on relative luminance and saliency with 20 px fixation radius

Brightness				Saliency			
Day		Night		Day		Night	
F1D	51.78%	F1N	60.87%	F1D	74.21%	F1N	75.28%
F2D	52.62%	F2N	68.59%	F2D	67.00%	F2N	78.28%
F3D	38.86%	F3N	62.91%	F3D	60.58%	F3N	81.96%
F4D	52.82%	F4N	64.22%	F4D	67.22%	F4N	80.15%
F5D	39.15%	F5N	64.30%	F5D	54.13%	F5N	72.87%
F6D	40.88%	F6N	66.59%	F6D	59.36%	F6N	72.34%
F7D	42.62%	F7N	67.64%	F7D	78.18%	F7N	75.61%
F8D	47.84%	F8N	62.29%	F8D	71.01%	F8N	79.85%
M1D	36.48%	M1N	61.85%	M1D	68.54%	M1N	78.01%
M2D	53.39%	M2N	61.74%	M2D	81.71%	M2N	82.18%
M3D	45.15%	M3N	51.70%	M3D	83.93%	M3N	81.04%
M4D	45.44%	M4N	64.88%	M4D	73.60%	M4N	79.35%
M5D	36.83%	M5N	65.51%	M5D	56.90%	M5N	77.43%
M6D	43.65%	M6N	65.15%	M6D	75.16%	M6N	77.29%
M7D	40.72%	M7N	69.18%	M7D	72.21%	M7N	77.18%
M8D	49.49%	M8N	58.05%	M8D	61.74%	M8N	73.58%
Mean	44.86%	Mean	63.47%	Mean	69.09%	Mean	77.65%

Table 5 Single sample *t*-tests between four groups of data and chance level (50%)

Measure	Time of day	*M* (*SD*)	*t*	df	Sig
Relative luminance	Day	47.73% (0.058)	−1.569	15	$P = 0.137$
	Night	68.45% (0.032)	23.050	15	$P < 0.001$**
Saliency	Day	70.00% (0.086)	9.303	15	$P < 0.001$**
	Night	78.21% (0.030)	37.218	15	$P < 0.001$**

*$P < 0.05$. **$P < 0.001$.

Table 6 Paired sample *t*-tests between relative luminance and saliency

	M (*SD*)	*t*	df	Sig
Relative luminance at day vs. saliency at day	−0.223 (0.078)	−11.411	15	$P < 0.001$**
Relative luminance at night vs. saliency at night	−0.098 (0.050)	−7.781	15	$P < 0.001$**

*$P < 0.05$. **$P < 0.001$.

Table 7 Paired sample *t*-tests between day and night

	M (*SD*)	*t*	df	Sig
Relative luminance at day vs. Relative luminance at night	−0.207 (0.074)	−11.228	15	$P < 0.001$**
Saliency at day vs. Saliency at night	−0.082 (0.077)	−4.253	15	$P = 0.001$*

*$P < 0.05$. **$P < 0.001$.

distribution at daytime might be inhibited by the sky area.

The sky areas in the target images are constantly brightening. Therefore, the fixation distribution might be 'inhibited' to the lower end of relative luminance because the sky has little visual information to be fixated. Image matting was performed for the data of all 16 participants on the target images to verify the effect of sky area. Liu *et al.* provided a method of image edge segmentation based on connected regions and statistical characteristics, which was used for reference here.[33] For each pixel in the distinguished sky area of every target image, the RGB value was replaced by average RGB value of the original image. An example of an original target image with normal sky area and the adjusted image is shown in Figure 7.

Target images from all videos at day were processed. Similar procedures for calculating mean percentiles of fixations across relative luminance were carried out to obtain adjusted relative luminance percentile. The original relative luminance percentiles and adjusted ones from the 16 videos are shown in Table 8. A slightly high trend of mean relative luminance percentile after adjustment (=0.61%) can be observed, but far from the significant level. These results are not in agreement with the conjecture that the sky has influence on the fixation distribution across relative luminance. This suggests that the previous results without adjustment on the sky are still valid.

According to the results presented in Figure 5 and Table 3, the correlation is found to be stronger on saliency than on relative luminance and at night than at day.

Table 8 Mean fixation percentiles of original and adjusted target images

Video	Original images (%)	Adjusted images	Difference after adjustment
F1D	55.86	56.00	0.14
F2D	55.41	55.96	0.55
F3D	41.97	42.08	0.11
F4D	53.43	57.50	4.07
F5D	41.37	41.41	0.04
F6D	42.87	43.19	0.32
F7D	45.23	46.68	1.45
F8D	50.81	51.06	0.25
M1D	39.41	40.31	0.90
M2D	57.40	57.62	0.22
M3D	47.37	47.38	0.01
M4D	47.81	47.98	0.17
M5D	40.77	40.79	0.02
M6D	46.80	46.89	0.09
M7D	45.65	46.85	1.20
M8D	51.54	51.71	0.17
Mean	47.73	48.34	0.61

Figure 7 An original target image (*left*) and the sky-adjusted image (*right*)

Table 9 Accumulative probabilities of fixations above a particular percentile at day and night

Percentile above	50th	55th	60th	65th	70th	75th	80th
Probability at day	83.46%	79.40%	73.92%	67.56%	60.26%	52.29%	42.78%
Probability at night	91.76%	88.91%	85.39%	80.99%	75.21%	67.95%	58.43%

For those studies assuming that relative luminance or saliency is an indicator for predicting fixation, it is necessary to evaluate the accuracy of prediction.

One way of evaluating efficiency of saliency as predictive indicator is to verify the accumulative accuracy of prediction. Accumulative probabilities of fixations that fall into the upper end of saliency above a particular percentile (50th to 80th percentiles at intervals of 5) at day and night are shown in Table 9. It can be observed that more than 80% of fixations fall into the areas of target images where the saliency is above the 50th percentile. When it comes to 70th percentile, such accumulative probability is still higher than 60% at day and 75% at night. The data provide quantitative evidence supporting that saliency is an effective indicator in predicting the distribution of fixations.

There are some limitations to this work. The calculation of luminance/saliency at all locations was based only on the eye-trackers' scene camera, which ignored the impact of the environment outside the camera view. The data were extracted based on static image, in which object motion was inherently excluded. Though object motion information is significant to draw visual attention, the impact of object motion on pedestrian's fixation cannot be revealed by current results. The accuracy of sky segmentation might be improved by applying advanced algorithm, such as machine learning. Further work is expected in exploring new indicator, better than saliency or comprehensive indicator, which combines saliency and relative luminance via tools like Bayesian probability models.

5. Conclusion

This study focuses on the relative luminance and saliency of the visual scene and its correlation with the distribution of fixation for pedestrians. Field experiments using mobile ETG were conducted in outdoor streets during day and night for 16 participants. The results show a clear tendency that pedestrians' fixations within 2° and 10° viewing angle are distributed in bright and significantly salient areas in the field of vision. More significant tendency was found in saliency than in relative luminance and at night-time than at daytime. Statistical analyses indicate that mean percentiles of fixation distribution on saliency at day, as well as relative luminance and saliency at night, have significant difference with 50% chance level, whereas 'relative luminance at day' does not. No effect of gender was found in terms of fixation pattern across relative luminance or saliency.

The correlation found between relative luminance/saliency and fixation distribution suggests that relative luminance/saliency may attract general visual attention of pedestrians in the outdoor lighting environment. It will improve the visual environment, including lighting and guiding facilities for pedestrian, especially at night. These findings also provide supportive empirical evidence for past studies assuming saliency is an ideal predictive parameter of fixation. Further work on combining indicator based on relative luminance and saliency is encouraged for fixation prediction at a more precise level.

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