Background lighting clutters: How do they affect visual saliency of urban objects?

The current study aims to create some general guidance for designers to better understand the impact of background lighting in their design and as a result minimise its effect on the visual saliency of urban objects. There are few studies about how lighting clutters can affect and decrease the visual saliency of illuminated urban objects at night. Lack of information in this area has resulted in increasing luminance to be recognised as one of the main tools to enhance the saliency of urban objects at night. To address this matter a study was performed to investigate the effect of proximity of lighting clutters on visual saliency of urban objects. A forced choice pair comparison method was employed, in which two test images of an urban object in different conditions of luminance contrast and proximity of light patterns were compared. Test participants reported in which image the target appeared more salient. Results show there is a progressive increase in saliency value by increasing the gap between the target and the background lighting when the luminance contrast of the target is 3 or higher. However, the critical area around the object with the highest effect lies between 0.5^{o} and 1^{o} visual angle. Removing light patterns beyond that point creates negligible effect. The findings of this study could inform development of future models of visual recognition in the road environment, models which can address the important effects of environmental context in addition to photometric variables (luminance and contrast) that are the only factors considered in traditional models of "Visibility Level".

Keywords: Urban lighting, cluttered background; conspicuity; saliency; proximity; light patterns

1. Introduction

Lighting designers usually increase the visual saliency of urban objects by increasing illuminance level applied on the object at night. Visual salience is the perceptual quality which makes some items in a scene stand out and immediately grab attention (L. Itti, 2005; L Itti, Koch, & Niebur, 2002). However, insufficient guidance and planning control in this regard could lead to a “light war” between competing illuminated objects in the nightscape of the cities(Davoudian, 2011). Existing guidelines (e.g. the ILP Outdoor Lighting Guide(ILP, 2005)) recommend a luminance ratio between an object and its background according to the degree of conspicuity (saliency) required, with a higher luminance contrast being recommended for a higher degree of conspicuity. Other important factors for the effect of background against which the target appears are the area and colour of the background (Boyce, 2008). As a general rule, it is also suggested that the larger the area around the target that is of a similar luminance to the target and neutral in colour, the smaller will be the threshold measure for conspicuity (Boyce, 2008; Driggers, 2003). So far, however, there has been little discussion about the design of lighting context, and its role in creating a cluttered background has been almost neglected. Davoudian investigated the effect of density of background light patterns on visual saliency (Davoudian, 2011). In this study, lighting context is not limited to luminance and colour of the background. Light fittings located at the scene and also the two-dimensional patterns of light on surfaces are also assumed as important factors of background lighting which could contribute to a cluttered background. The results of that study showed that background light patterns affect visual saliency of urban objects and increasing density of light patterns results in a decrease in the level of saliency. The current study was designed to further evaluate the effect of background light patterns on visual saliency of urban objects. This paper focuses on the role of proximity of the background lighting clutter as one of the influential factors in the visual saliency of urban objects.

2. Proximity of Light Patterns to Target Object and Visual Saliency

Visual salience is the perceptual quality which makes some items in a scene stand out and immediately grab attention (L. Itti, 2005; L Itti, et al., 2002). It is known that visual conspicuity/saliency of an object not only relies on its own properties such as local feature contrast (e.g. colour contrast and brightness contrast) (Adrian & Eberbach, 1968/69; Aks & Enns, 1996; Bloomfield, 1972; Eckstein, Ahumada, & Watson, 1997; H. C. Nothdurft, 1992; Paulmier, Brusque, Carta, & Nguyen, 2001){Driggers, 2003 #124} but also context of an object has an effective role in visual conspicuity/saliency (Biederman, Mezzanotte, & Rabinowitz, 1982; Chun, 2005; Gibson & Jiang, 2001; Palmer, 1975; Wolfe, Oliva, Horowitz, Butcher, & Bompas, 2002). Moreover, background clutter has been found as one of the factors in reducing objects conspicuity in urban areas and during night (Ho, Scialfa, Caird, & Graw, 2001; Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006).

Brown and Monk , in a visual search task, by using highly specific configurations of non-targets in the target surroundings, showed that congested target surrounds act to camouflage the target and decrease visual search performance (Brown & Monk, 1975). It is also known that gaps are strong salience markers (Mori, 1997; Treisman & Souther, 1985); creating a gap between target and the continuous background elements creates saliency and this is one of the methods that designers – including lighting designers – use to elevate the visual importance (saliency) of an object. However, other stimulus properties that coincide with the occurrence of gaps might also affect saliency (Caelli & Oraglia, 1985).

Target salience is modulated by the distance to neighbouring elements; however, this modulation only occurs over a limited distance (H.C. Nothdurft, 2005). Eriksen and Hoffman show that non-target elements significantly affect the conspicuity of the target, when they lie within 1 degree visual angle of the target. On the other hand, as noted by Eriksen and Eriksen, distracters have little or no effect when presented at more distant locations (B. A. Eriksen & Eriksen, 1974). In their study they attempted to understand the effect of noise on target identification when no visual search is required. They examined whether the spacing between a letter that always appears in the same known location and noise letters surrounding it could affect identification of the target letter. They employed three different proximity levels between the target letter and noise letters: 0.06, 0.5 and 1 degree visual angle. Their results showed a significant decrease in reaction time and errors in recognition of the target by increasing the spacing between the target and noise letters. However, they did not report whether the reaction time and errors also significantly decreased between proximity levels and whether this effect was constant between different proximity levels. Exploring the graphs and tables they provided, however, shows a decrease in the effect of proximity between 0.5 and 1 degree visual angle compared to the effect between 0.06 and 0.5 degree.

Studies show that the size of effect relies on the nature of target and non-targets and the way they are placed in the set (e.g. (Kramer & Jacobson, 1991; H.-C. Nothdurft, 2000)). Kramer and Jacobson used a vertical line as a target between other horizontal and vertical distractor lines and found that the extent to which non-target elements interfered with conspicuity of a target depended on whether the non-targets can be interpreted as being part of other objects in the scene (producing smaller interference effects) or if they were joined and interpreted with the target. For example non-targets which are segments of a line including the target (producing large effects) (Kramer & Jacobson, 1991). There are, however, exceptions in the impact of proximity. For example, a target that differs in orientation from neighbouring lines is detected faster when lines are placed close together rather than being widely spaced (H.-C. Nothdurft, 2000).

Further experimental work was undertaken to extend the evidence on the impact of proximity of non-targets to target objects and saliency value. It should be noted that majority of studies in this regard focused on visual search tasks and are often performed on standardised abstract stimuli on threshold visibility level. This study focuses on the judgment of saliency of targets which are in supra threshold visibility levels and real prominent urban features such as urban monuments and landmarks. Background objects are patterns of light in the target surroundings.

3. Method

A forced choice pair comparison test was carried out to rank the visual saliency of urban objects observed with different levels of luminance contrast and proximity levels of background light patterns.

3.1. Apparatus

Photographic and computer generated images have been established as valid surrogates for on-site experiences by representing the scenic quality of the onsite observation in different circumstances and used by many researchers [e.g. (Schapter, 1999; Stamps, 1990)]. This study used and modified two black and white images of night-time urban scenes. Scene 1 subtended a visual field of 24° width and 18° height at the observer's eye; Scene 2 was 26° wide and 20° high. Selection of urban scene were based on the apparent size, viewing distance (middle to background zones), and images sharpness and viewing position (the view points in both scenes are the middle of the image and from a human viewpoint of the scene). Urban objects were imposed to the images and were not part of the original images. The images have great flexibility to be modified to fit the study's requirements, such as flexibility of adding and removing light patterns without damaging the fundamental characteristics of the scene. In both images, an urban sculpture was used as the target as shown in Figure 1.

Figure 1. Sample of Scene 1 (left) and 2 (right) with target objects marked

The target objects were not identical but did present the same width (1°) and height (3°), a size sufficiently large to gain attention at first glance. The objects are located slightly off-axis from the central vertical axis of the image. When a still picture is viewed, it feels more comfortable and psychologically balanced scanning the picture along a central horizontal line as if there was an invisible visual axis across the picture {Shang, 2000 #277}. Accordingly, a judgment was made that the test objects should be positioned in a region on the central horizontal axis. The images were presented using a pair of identical computer monitors (Viglen VD 695, 15 inch screen, resolution 1280 x 1024 / 60 Hz, Dot Pitch / Pixel Pitch 0.24 mm). Microsoft PowerPoint was used to present the images.

Four different levels of proximity of light patterns from the object were considered; 0, 0.5, 1, 2 degree visual angle. These numbers are used as they are a coefficient of the width of the target object, meaning

$D0=0$, $D0.5=\alpha^o/2$, $D1=\alpha^o$ and $D2=2\alpha^o$

In which α is the degree visual angle of the target object width. In each level, all patterns of light in that radius around the object are removed (Figure 2 & 3). In this study higher the proximity level means further away the light patterns are from the urban object.

Figure 2. Scene 1. Sample of images in different Proximity Conditions. Target object in all images has luminance contrast of 5: a. Proximity D0, b. Proximity D0.5, c. Proximity D1 and d. Proximity D2

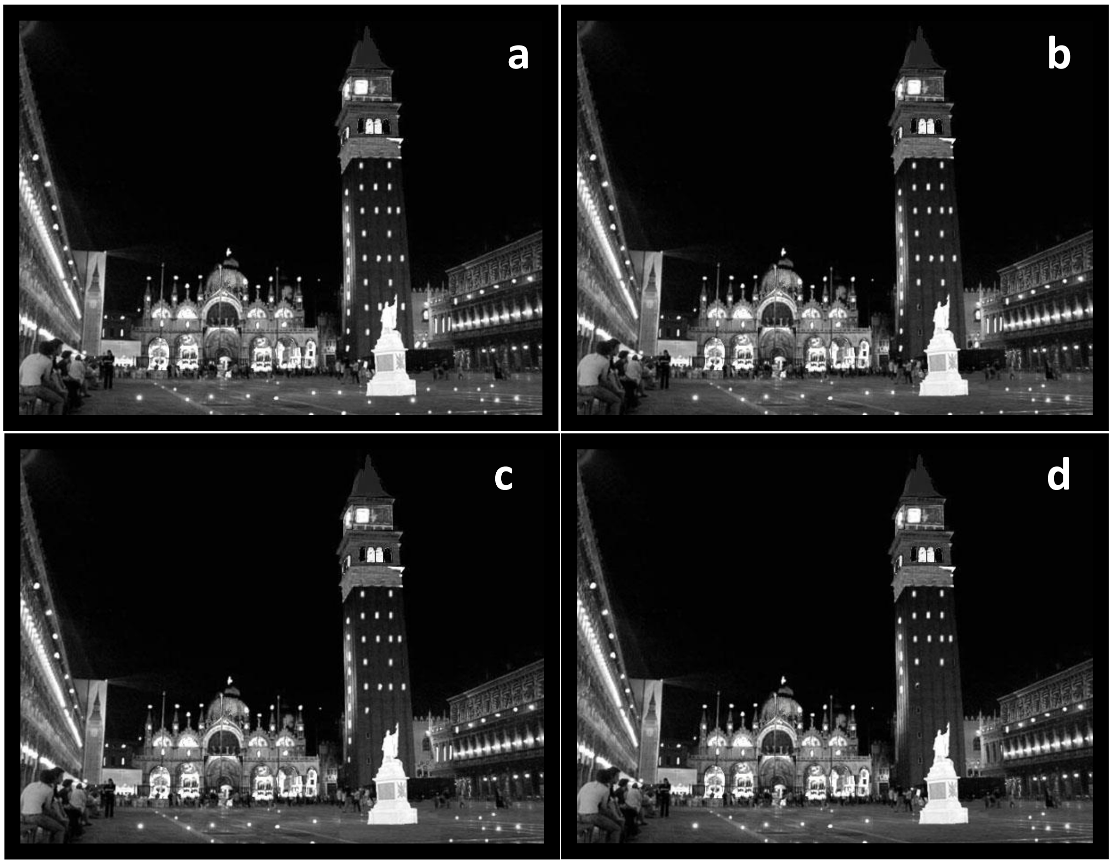

Figure 3. Scene 2. Sample of images in different Proximity Conditions. Target object in all images has luminance contrast of 5: a. Proximity D0, b. Proximity D0.5, c. Proximity D1 and d. Proximity D2

Density of background light patterns is constant and light patterns are distributed evenly on the background by the method used by Davoudian (Davoudian, 2011). In her study, a grid was imposed over the images used and the number of boxes and area occupied by light patterns were controlled (Davoudian, 2010).

Saliency was examined using images presenting four levels of proximity of light patterns and four levels of target-background luminance contrast: the two urban scenes were digitally manipulated to present all 16 possible combinations of luminance contrast and proximity for each scene.

Luminance contrasts of 0, 3, 5, 10 were used, these being suggested to give effects that are: not noticeable, just noticeable, low drama and high drama, respectively (ILP, 2005). It should be noted that due to non uniformity of the target object and background, average luminance was calculated. Luminances were determined using pixel brightness values from Photoshop (Hagiwara, Kizaka, & Fujita, 2004; Kimura & Noguchi, 2002; Moore, Graves, Perry, & Carter, 2000). Luminance contrasts were determined using the standard expression $C_L = (|L_T - L_B|)/L_B$. Where L_T is the average pixel brightness of the target and L_B is average pixel brightness of the whole scene other than the target.

The mean pixel brightness of the target background is shown in Table 1. While there was an attempt to maintain similar background luminances for all variations of background density it can be seen that background luminances vary slightly.

BGD Level	**Mean Pixel Brightness**	**Std Dev**
Scene 1	52.98	57.78
Scene 2	38.64	53.16

Table.1. Mean and standard deviation of background luminance

The tests were carried out in a laboratory in which the artificial lighting was not switched on and daylight was excluded using blinds. A 40W GLS lamp was used to provide a low level of background lighting, similar to night-time conditions, and this was located to avoid glare on subjects' eyes or reflections on display screens. The background lighting produced an average illuminance of 5.6 lux on the front of the table upon which the PC display screens were placed.

Thirty volunteer subjects were recruited. These were mostly students of the University of Sheffield, School of Architecture and 18 were male. Age range was between 25 and 45 years and all reported normal or corrected vision. Half of the sample undertook tests using only Scene 1, the other half saw only Scene 2.

A forced choice method was employed, in which two test images were presented in juxtaposition. Test participants were required to report in which image the urban object appeared more salient.

A 20- minute adaptation time was allowed before trials, during which test instructions were delivered. A test commenced with between five and ten practise trials of the main experiment images, continuing until the subject reported confidence with the procedure.

The 16 different versions of each image were compared in all possible pairs, thus requiring 120 comparisons to be made. Each pair of images was shown for a maximum of 10 seconds and there were black screen intervals between successive pairs. Two test images were presented simultaneously on side-by-side monitors and test participants reported whether the left-hand or right-hand monitor presented the image with the more salient target. A score of 1 was given to the image reported to be more salient and a score of 0 given to the second image.

The anticipated number of 'left' and 'right' responses was balanced to counter a stimulus frequency bias. To reduce sequential contraction bias, presentation order was randomised; to counter positional bias, left-hand and right-hand locations of image pairs were balanced (Poulton, 1989). Null condition trials were included within the series of test images to allow analysis for experimental bias in which identical images were shown in both spatial locations (i.e. both monitors). Results show no bias towards any of the monitors in spatial method (Davoudian, 2010). The study was carried out with compliance to standard ethical procedure of University of Sheffield.

4. Results

4.1. Saliency value

As mentioned earlier, in trials, a score of 1 was given to the image reported to be more salient and a score of 0 given to the second image. A summation of these results for each of the 16 variations of a test image provides a saliency value, with a high saliency value indicating an image in which the target appears to be more salient than images with lower saliency values.

The Mann-Whitney test does not suggest any significant differences between the results obtained from two scenes, $p>0.05$, however the results of both scenes will be presented separately for more clarity. These results are shown in Figure 4.

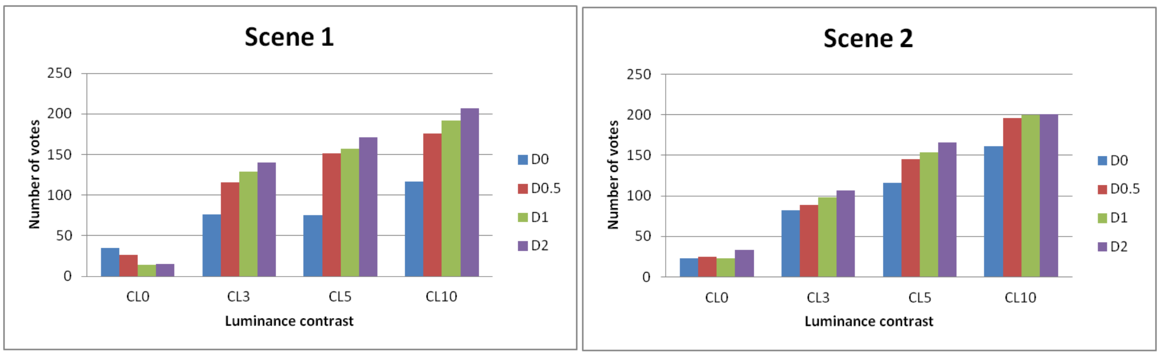

Figure 4. Saliency values of the target object (number of votes) in different levels of proximity and luminance. Error bars are with standard deviation.

As expected, the target tends to become more salient as target-background luminance contrast increases, and the target becomes less salient as the proximity level of background light patterns decreases.

Saliency values in different proximity levels are illustrated in Figure 5. This suggests a trend for saliency to increase as the proximity of background light patterns increases; however, it appears that the impact of proximity decreases over levels.

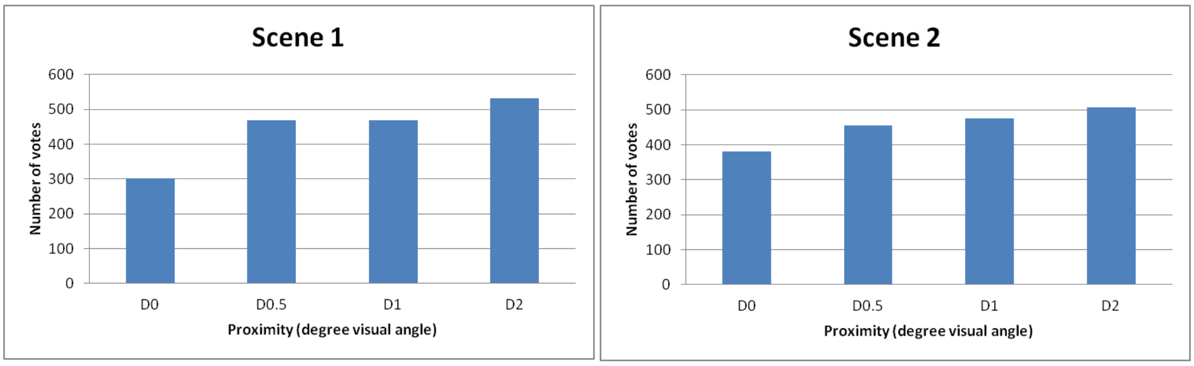

Figure 5. Saliency values of the target object (number of votes) in the different levels of proximity. Error bars are with standard deviation.

Cochran's Q test suggests significant differences of saliency between the four levels of proximity of background light patterns for both scenes, $p<0.01$.

However, breaking down the data from different luminance contrasts yields slightly different results. In luminance contrast 0, the Cochran's Q test shows no significant impact of proximity on saliency of the urban objects in Scene 2, $p>0.05$, while Scene 1 shows a significant effect of proximity at luminance contrast of 0, $p<0.01$. However, when there is a luminance contrast between the object and its background and the luminance contrast is constant, the impact of proximity is significant, $p<0.01$.

The McNemar test (Field, 2013) was used to examine whether the differences between the saliency values of two immediate proximity levels are significant. Results are shown in Table

2. Adjustment of threshold p-value ($p<0.01$) to compensate the risk of falsely indicating a significant was considered (Dunnett, 1955).

Compared Proximity Levels		0 & 0.5	0.5 & 1	1 & 2
McNemar test	p value, Scene 1	<0.01	1.000	<0.01
	p value, Scene 2	<0.01	0.249	<0.01

Table 2. Comparison between the results of different levels of proximity.

The progressive trends of votes by increasing the proximity level could be seen only in conditions where there is a luminance contrast between the target and background. The results from Scene 2 show that when there is no luminance contrast between the target and background (CL=0), proximity does not affect the saliency. The results of Scene 1 show a significant effect of proximity in the absence of luminance contrast, however, the trend is in opposite direction of the results when there is a luminance contrast between the target and background (Figure. 4).

From this point further analysis has been carried out only on conditions where the luminance contrast is presented.

4.2. Correlation between Proximity of Light Patterns and Saliency Value

Partial correlation test was used to examine whether the changes in saliency value imply a correlation between proximity of light patterns and saliency value. The results of correlation analysis are presented in Table 3. Results show that saliency value of the target is significantly correlated with the proximity level of light patterns, $p<0.01$. Correlation between luminance contrast and saliency value was also tested. As expected, there is a significant relationship between saliency value and level of luminance contrast, $p<0.01$. This suggests that proximity accounts for 31.5% of variance in saliency value, while luminance contrast accounts for 43.2% of variances in saliency value.

Correlation test	r	r2	p value
Between Saliency Value and Proximity while CL and Scene number is controlled	0.562	0.315	<0.01
Between Saliency Value and CL while Proximity and Scene number is controlled	0.657	0.432	<0.01
Between Saliency Value and Scene number while Proximity and CL is controlled	n/a	n/a	0.604

Table 3. Results from correlation test between saliency value, proximity and luminance contrast

5. Discussion and Conclusion

This study set out with the aim of assessing the effect of proximity of background light patterns on the visual saliency of urban object. Results show a progressive increase in saliency value with increasing the size of a clear area around the target when the luminance contrast is 3 or higher. Proximity accounts for 31.5% of variance in saliency value. However, the critical area around the object with the highest effect lies between 0.5^{o} and 1^{o} visual angle. Removing light patterns beyond that point affects the visual saliency, but this effect is very small.

The above findings are in agreement with the research performed by Eriksen & Hoffman (C. Eriksen & Hoffman, 1972). They show that non-target elements significantly affect the conspicuity of the target, when they lie within 1 degree of visual angle of the target and the most impact is in 0.5 degree visual angle. Distracters, however, have little or no effect when presented at more distant locations (B. A. Eriksen & Eriksen, 1974; C. Eriksen & Hoffman, 1972). It should, however, be taken into consideration that set size can affect this result. It is possible that by increasing set size and/or target size a larger gap between the object and background patterns might be required.

The findings of this study – if confirmed by similar investigations - could inform development of future models of visual recognition in the road environment, models which can address the important effects of environmental context in addition to photometric variables (luminance and contrast) that are the only factors considered in traditional models of "Visibility Level". The results of this research could also be an important and necessary direction for future work. For example, there might be a future examination of "salience" of other types of targets – such as traffic lights or traffic signs, and perhaps the effects of target motion or colour.

The current study adds further evidence on the role of background lighting design on the visual saliency of urban objects. Identification of the impact of background lighting design factors on the appearance of urban objects makes it possible for this study to suggest that the significant lighting factors go beyond those normally presented. This includes elements in lighting literature such as luminance and colour contrast and uniformity or non-uniformity of the background lighting. The current Guidelines (e.g. the ILP Outdoor Lighting Guide 2005) consider only a traditional lighting measurement of background lighting. The results of the present study suggest that the current Guidelines should also consider visual characteristics of the lighting context; such as presence of light patterns (in form of light sources, etc) in the close proximity of objects.

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BGD Level	Mean Pixel Brightness	Std Dev
Scene 1	52.98	57.78
Scene 2	38.64	53.16

Table.1. Mean, standard deviation and median of background luminance

Compared Proximity Levels		0 & 0.5	0.5 & 1	1 & 2
McNemar test	p value, Scene 1	<0.01	1.000	<0.01
	p value, Scene 2	<0.01	0.249	<0.01

Table 2. Comparison between the results of different levels of proximity.

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Figure 2. Sample of Scene 1 (left) and 2 (right) with target objects marked

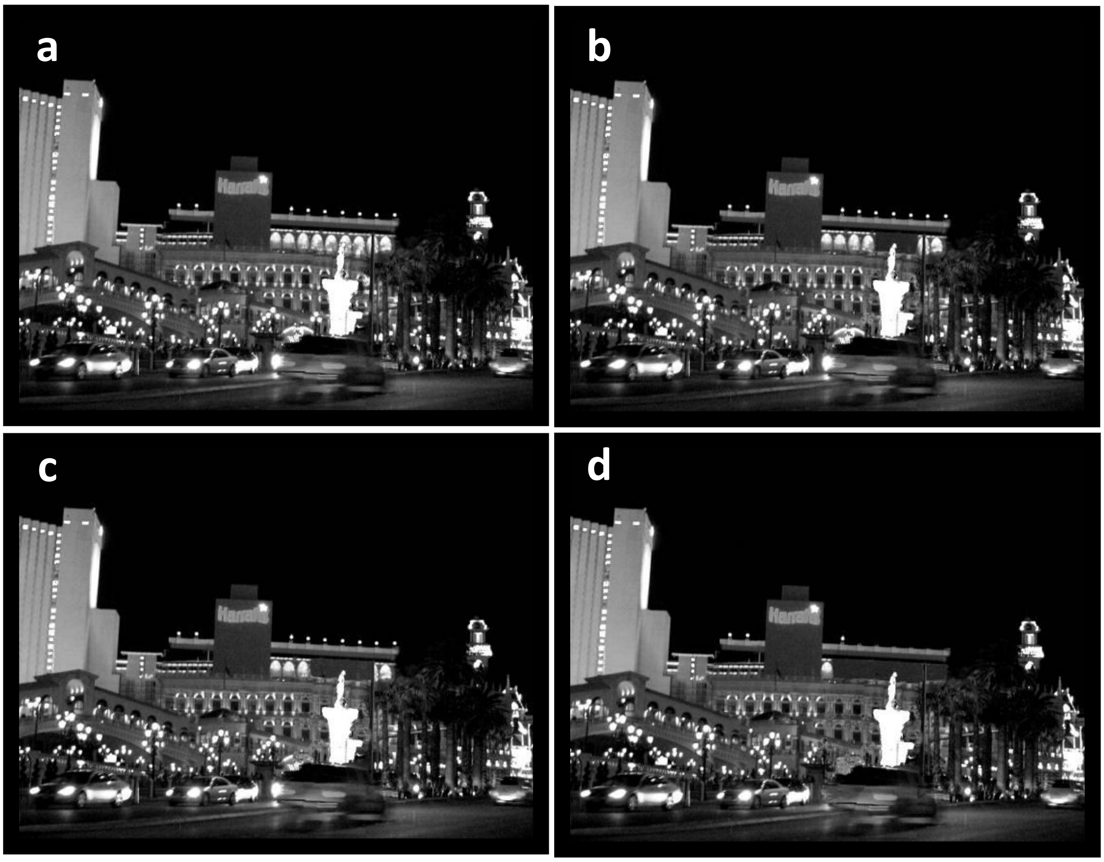

Figure 2. Scene 1. Sample of images in different Proximity Conditions. Target object in all images has luminance contrast of 5: a. Proximity D0, b. Proximity D0.5, c. Proximity D1 and d. Proximity D2

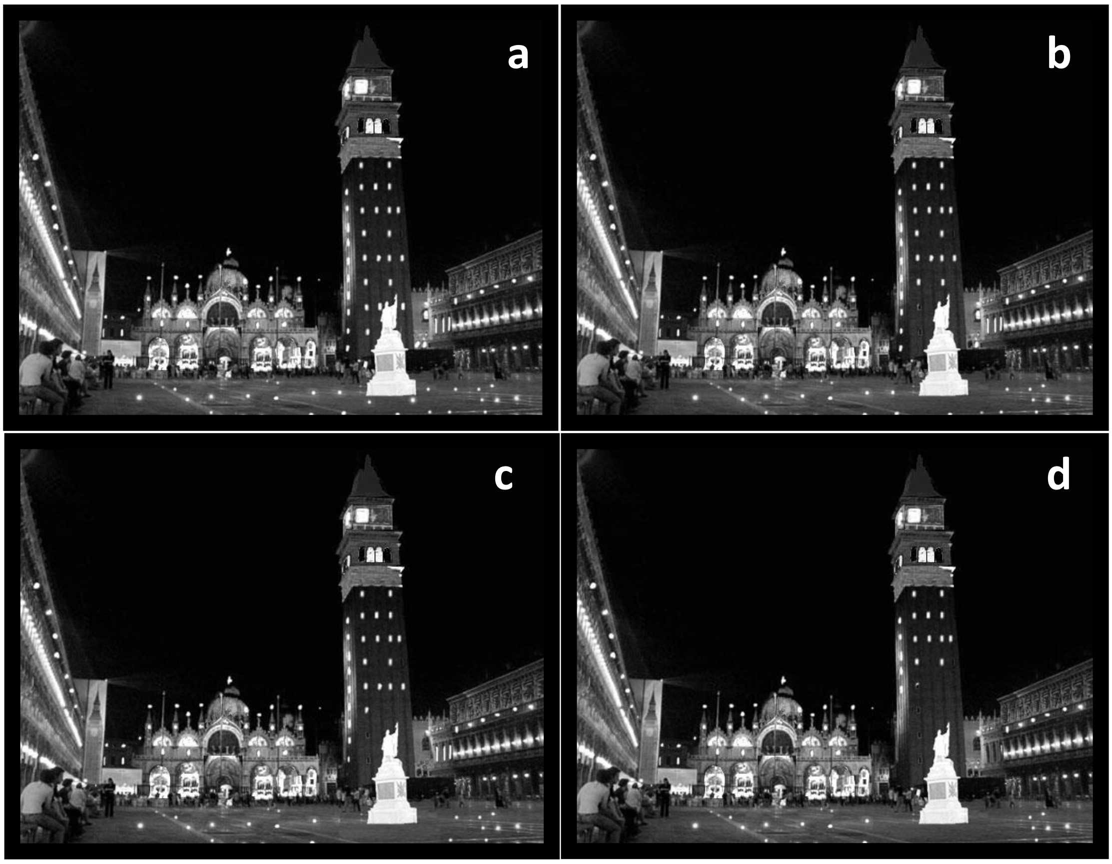

Figure 3. Scene 2. Sample of images in different Proximity Conditions. Target object in all images has luminance contrast of 5: a. Proximity D0, b. Proximity D0.5, c. Proximity D1 and d. Proximity D2

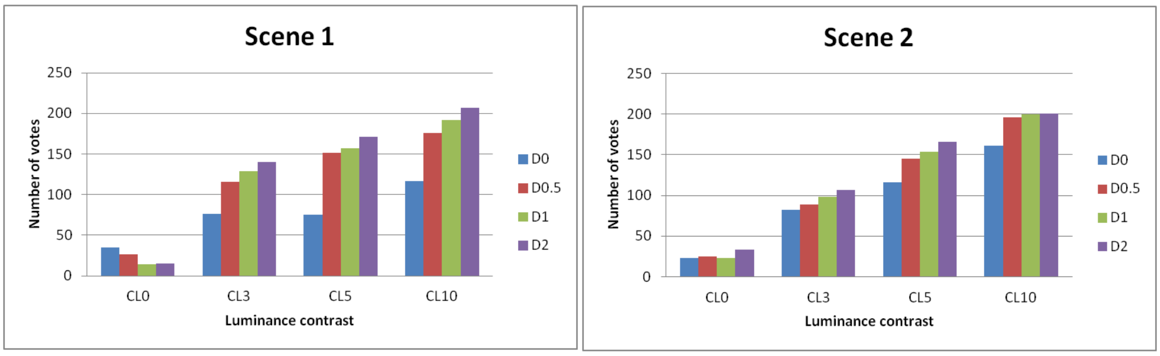

Figure 4. Saliency value of target (number of votes) object in different levels of proximity and luminance. Error bars are with standard deviation.

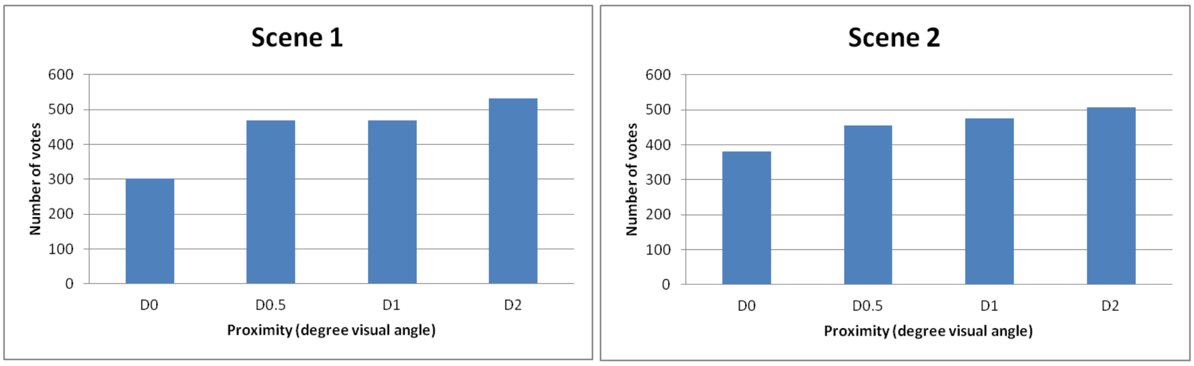

Figure 5. Saliency value of the target object (number of votes) in the different levels of proximity. Error bars are with standard deviation.