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Effects of the viewing context on target detection. Implications for road lighting design

Anaïs Mayeur [a,b], Roland Brémond [a,*], J.M. Christian Bastien [c]

[a] Université Paris Est, LEPSiS, INRETS-LCPC, Paris, France
[b] Université Paris Descartes, ECI, Paris, France
[c] Université Paul Verlaine, ETIC, Metz, France

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ABSTRACT

The Small Target Visibility (STV) model is the main model used to assess the quality of road lighting installations (IESNA, 2000). However, this model is based on a simple detection task in foveal vision using psychophysical data from laboratory conditions. The purpose of this study was to evaluate the impact of a complex background and apparent motion on target detection performance in mesopic vision, for three luminance contrasts, with reference to the STV scenario. To do so, participants were invited to detect standard square targets varying in terms of contrast presented in three Conditions: a uniform background, still images, and a video. Luminance levels were chosen in the mesopic domain relevant for road lighting at night. Images and video were chosen in relation to a driving task at night. The results showed that both the spatial context and the apparent motion had a negative impact on peripheral target detection performance: contrasts which are easy to detect in conditions close to the STV reference data may lead to poor performance if one adds context variables. These results give evidence that the STV model used for road lighting design based on laboratory data is limited, which strengthens previous results (Mayeur et al., 2008). The results are discussed in relation to the field factor used by practitioners to compensate for the differences between the STV reference scenario (detection of a small square target on a lit road while driving) and the STV psychophysical reference data.

1. Introduction

1.1. Night-time road safety and road lighting

Night road lighting is generally considered to have a positive effect on road safety, and at the same time to contribute to the traffic throughput. However, the relation between road lighting and road safety is much debated. Some authors have shown that risk compensation (Wilde, 1984) may lead to an increase in speed and a decrease of diffuse attention on lighted roads, which in turn may reduce road safety (e.g. Assum et al., 1999). Some studies found no change in average speed when road lighting was introduced, while other showed the contrary. Recently, Wanvik (2009) showed that for all Dutch roads, the mean effect of road lighting on injury accidents during the hours of darkness was −50%. An overview of 62 field studies from 15 countries made by the *Commission Internationale de l'Eclairage* (CIE) showed a positive correlation between road lighting and road safety (CIE, 1992). From the 23 before-and-after studies of this review, the average effect of road lighting was a 30% reduction in night-time injury accidents. A restriction to this was that a bad design could be worse than no lighting at all (Mace and Porter, 2004; Van Bommel and Tekelenburg, 1986).

All of these field studies seem to suffer from a number of biases, such as changes in the driver populations between night and day, changes in trip motivations, in driver behaviours, chrono-biological effects, etc. For instance, Assum et al. (1999) commented that people driving during darkness and daylight hours are not the same. Thus, even though the safety effects of road lighting have been studied extensively, it is difficult to compare and generalize the findings, and to compensate for the methodological biases (Elvik, 2002).

If one of the causes of the high night-to-day accident ratio is the inability of drivers to detect and recognize obstacles at an early stage to adapt their trajectories, then lighting systems should allow target detection at any point of the road surface, allowing drivers to react to emergency situations and changing environments (e.g. curves), thus increasing the accident – avoidance performance.

Visual data are essential in the sensory-motor regulation of the driving activity (Hills, 1980; Sivak, 1996), including the collection of

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* Correspondence to: Roland Brémond, LEPSIS, Laboratoire Central des Ponts et Chaussées, 58 bd Lefebvre, 75015 Paris, France.
E-mail address: roland.bremond@lcpc.fr (R. Brémond).

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relevant information to react to unexpected events through the perception-action regulation (Bellet et al., 2009). The collection of relevant visual information addresses two among the three levels of the driving activity, according to the hierarchical model of Allen et al. (1971). At the vehicle control level, the driver uses visual information in order to stay in a safe lane (e.g. Land and Lee, 1994), avoiding potential obstacles. At the tactical level, anticipation of other drivers' behaviour from perceptual data implies more cognitive inferences (Mundutéguy and Darses, 2007). A safe reaction to unexpected hazards addresses the control level of Allen *et al.*'s model. It implies that dangerous situations are detected and understood far enough in advance so as to allow drivers to react correctly, that is, to allow drivers to anticipate accidents and to correct their current trajectory (Gibson and Crooks, 1938). Such anticipation benefits from a lower temporal pressure, allowing the drivers to improve their decisions (Hoc and Amalberti, 2007).

Road lighting aims at increasing the available reaction time to unexpected hazards on the road. The earlier the detection, the more time is left for the subsequent subtasks of object identification/classification and avoidance.

1.2. The Small Target Visibility (STV) model

To quantify lighting quality, the link between driver's perception and the lighting system is operationalized by photometry. This includes the use of psychophysical models of human visual performance, in order to select the relevant parameters and to set the required performance levels (photometric thresholds). Several parameters (illuminance, luminance, Visibility Level, etc.) have been proposed so far for road lighting design in the scientific and technical literature (Brémond, 2007), including the CIE and the *Illuminating Engineering Society of North America* (IESNA). The purpose of these indexes is to rate the visibility from photometric measurements, instead of performing visual tests with human observers.

The Visibility Level (VL) is proposed as a quality index in the American standard (IESNA, 2000) and French standard (AFE, 2002), but not in the European standard (European Norm, 2004–2005). The VL is computed as the ratio between the measured contrast ΔL (between the target and its background, that is, the road surface) and the contrast threshold ΔL_t (Adrian, 1989, 2004). This threshold is computed in Adrian's model from data collected in laboratory conditions (e.g. Blackwell, 1946).

For example, VL = means that the target's luminance contrast is 7 times the contrast needed for object detection for a standard observer in laboratory conditions. The STV model uses a reference scenario related to the road lighting purpose: to enhance unexpected hazards visibility on the road. More precisely, road lighting should allow the driver's detection of a 50% reflectance square target of 0.18 m height at 83 m, which is understood as a distance where s/he uses to pick up relevant information. The VL is computed (Adrian, 1989) from the photometric measurement of the target and background (road surface) luminance, for a 60 years old driver, assuming that the target is displayed during 0.2 s. Then, the American Standard (IESNA, 2000) provides minimal values (STV criteria) for various road categories (e.g. freeway, expressway, etc.) for the mean VL over various target locations.

Although these conditions are far from a "real" driving situation, engineers assess the lighting system quality by comparing measured STV to the STV criteria (also known as field factors), which are specific to the driving task (see also CIE, 1981).

1.3. A multi-factor approach to improve road lighting design

A number of factors obviously separate the reference scenario (a driving performance) from the reference data recorded in laboratory conditions (Blackwell, 1946): flat uniform vs. realistic target (Lecocq, 1999), driving activity vs. single detection task (Mayeur et al., 2008), stimulus eccentricity vs. central vision (Mayeur et al., 2008), complex vs. uniform background, dynamic vs. static situation (in terms of self motion as well as optic flow), anticipation due to prior knowledge vs. abstract task, etc.

The standard hypothesis is that a so-called "field factor" would compensate for the difference between the laboratory and driving situations (CIE, 1981). However the lack of consensus about the field factor value leads to a dead-end. Collecting data in the reference (driving) scenario is very difficult, and depending on the experimental design, the impact of the above factors may vary in importance, and interact in different ways. Various field factor values are suggested, which vary between 1.6 and 30 (Adrian, 1987; AFE, 2002; Gallagher and Meguire, 1975; Hills, 1975; IESNA, 2000; Lecocq, 1999; Van Bommel and Tekelenburg, 1986).

To address this theoretical problem, our work contributes to fill-in the gap between the STV reference scenario (detection of a flat square target on a lighted road, at a given distance, while driving) and the STV reference data (detection of this standard target in laboratory conditions). We have investigated some among the most obvious parameters responsible for the difference between laboratory and driving performance, through appropriate and separate experiments.

In a first experiment (Mayeur et al., 2008) we assessed how adding a driving-related task affects target detection in peripheral vision, under mesopic conditions. The experimental design consisted of a three-phase experiment. In the first phase, two groups (control and experimental) performed a peripheral detection task (simple task), using the same square target as in the STV model in order to be consistent with both the STV reference scenario and STV reference data. A tracking task was performed in Phase 2 for both groups (moving a target along a circuit, on a screen). In the third phase, the control group performed the same task as in Phase 2. The experimental group performed a double task: a tracking (primary) task and a peripheral detection (secondary) task. In this experiment, the tracking task and the stimulus eccentricity had an effect on target detection. The tracking task caused detection performance to decrease from 84.2% to 67.5%, $p < 0.001$. These results showed that the STV model used in road lighting could be improved, by taking into account the effects of task and eccentricity of the stimuli on target detection.

In this paper, we designed a laboratory experiment in order to focus on another limitation of the STV reference data: the visual context of target presentation. We investigated two factors: (1) the complexity and semantics of the background, and (2) the apparent motion of the background, the other factors (including the target) being as close as possible to the reference STV scenario.

2. Method

2.1. Overview

The purpose of this study was to evaluate the impact of a complex background and of the apparent motion on target detection performance in mesopic vision, for various contrasts. Three Conditions were designed, from a reference psychophysical experiment (Condition 1) to a situation closer to driving (Condition 3, see Fig. 1).

Condition 1. This condition used a psychophysical protocol close to the one used by Blackwell (1946) and Mayeur et al. (2008). Blackwell's paper measured detection performance in foveal vision on a uniform background, while Mayeur et al. (2008) and the present experiment (Condition 1) considered eccentricities from 1.5° to 7°. Unlike Mayeur et al. (2008), the stimuli in Condition 1

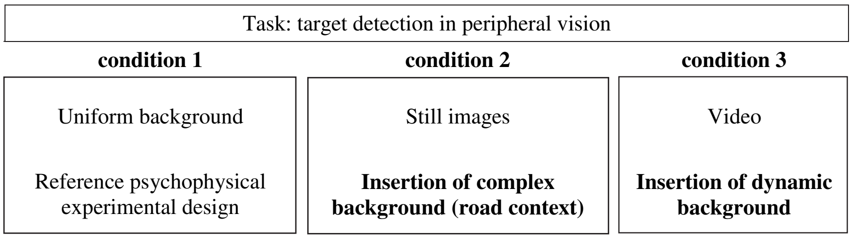

Fig. 1. Framework of the experimental design. These 3 conditions were counterbalanced using diagram balanced Latin squares resulting in 6 groups of participants.

were restricted to the lower half of the screen, in order to be consistent with Conditions 2 and 3 where the stimuli appeared on the road surface (see bellow). The subjects' task was to detect square targets with various contrasts and eccentricities on a uniform background. Eccentricity is defined as the angular distance (in degree) between the subject's fixation and the target. The purpose of this condition was to collect reference data for each participant, in conditions close to the laboratory data used in the STV model.

Condition 2. The aim of this condition was to measure target detection performance when the uniform background is replaced by photographs of urban streets at night. The luminance contrasts between the targets and the near background were the same in Conditions 1 and 2. Thus, by comparing these two Conditions, we were able to quantify the impact of a complex background on the detection task.

Condition 3. This condition consisted of the same detection task used in conditions 1 and 2. However, the background consisted of a video. While looking for targets on the road, the subjects were asked to mimic the control of the vehicle direction with a steering wheel. The purpose of this additional task was to put the subjects in a situation closer to driving, as road lighting indexes refer to driving. However, as there was no effect of steering the wheel on the video and no other input device (such as gas or brake pedal, gear lever, etc.), this task was considered as having little cognitive demand, and thus we assumed that it did not impact the detection performance. Moreover, as the targets only appeared on straight portions of the roads, the cognitive load of this task was as low as possible at the moment of target detection. The purpose of Condition 3 was to assess the impact of a dynamic background in comparison to the static background of Condition 2 on the detection task.

2.2. Subjects

Thirty-two adults (12 women and 20 men) with a mean age of 39.3 years old ($SD = 11.9$) participated to the experiment. They were all licensed drivers and had normal or optically corrected vision. They were recruited from the Laboratoire Central des Ponts et Chaussées and from the Paris Descartes University. All subjects were naive to the purposes of the experiment and were given a full explanation of the experimental procedures. A written informed consent was obtained before participation with the option to withdraw from the study at any time.

The experimental design allowed precluding the order effect by counterbalancing (using digram-balanced Latin square design) the 3 Conditions in 6 groups, with a control over possible order effects, such as practice or fatigue.

2.3. Apparatus and experimental room

2.3.1. Experimental room

The experiment took place in a room under controlled photometry (no window, walls painted in black). The subjects were sitting in an ergonomic seat that could be adjusted (Recaro Expert L). The seat was mounted on a platform which allowed to compensate for the subjects height. A pedal allowed to record the subject's answers (target detection) in the 3 Conditions; no confusion was reported about the use of this pedal. A steering wheel was added in Condition 3.

The square targets and the background images were displayed on a screen by a video-projector, with a geometric configuration leading to an angular field of view of 30 height (1.50 m) and 40 width (2 m) from the subject's position. The image resolution was 1280 × 1024, with a refresh rate of 60 Hz. A photometric calibration of the screen allowed computing the displayed luminance at any pixel of the images, including the targets and near background. For all conditions, the background luminance around the targets was mesopic (below 1.5 cd/m^2) which is consistent with road lighting practice. The photopic definition of the luminance was used, as the $V(\lambda)$ sensitivity function is accurate enough down to 0.1 cd/m^2 (Alferdinck, 2006).

A non-invasive binocular eye-tracking system (S.M.I. iViewX™ RED) was used to record the ocular fixations of the participants. The eye's pupil and corneal reflection positions were calculated with a sample frequency of 50 Hz (eye position was used to calculate target eccentricity, see Section 2.4.1).

2.3.2. Background images

In Condition 1, a black square fixation target (0.1 cd/m^2) of 0.25° of visual angle was presented in the middle of the screen. The stimuli were displayed on a uniform background (see Section 2.3.1). In Condition 2, the uniform background was replaced by road images at night, extracted from the video used in Condition 3. In Conditions 2 and 3, the fixation square was removed and the subjects could freely explore the images (Condition 2) and the video (Condition 3).

The video was recorded in an urban area (Paris, France) at night, with a JVC digital camera fixed in a car at the driver's eye level (see Fig. 2). The car followed two-lane streets at about 50 km/h. The images in Condition 2 were extracted from the video, so that the background images, target locations and visual contexts are the same for all stimuli in Conditions 2 and 3.

2.4. Stimuli

The target stimuli were uniform squares of 0.25° of visual angle, with various contrasts (0, 0.3, 1.2 and 4.8) with the near background. This non-realistic target was chosen in order to be consistent with the reference target used by road lighting engineers (AFE, 2002; IESNA, 2000), and was previously used in Mayeur et al. (2008). During Condition 1, the stimuli position was restricted to the lower half of the screen, in order to be consistent with Conditions 2 and 3 where the targets appeared on the road surface (see Fig. 3).

In Condition 1, after an acoustic signal (priming), a target appeared for 230 ms along different eccentricities and contrasts.

Fig. 2. Examples of street images at night extracted from the video.

One hundred twenty (120) stimuli (10 presentations × 3 Eccentricities × 4 Contrasts) were presented randomly to each participant. The delay between the priming and the stimulus appearance was randomly chosen between 1 and 4 s.

In Conditions 2 and 3, the timing for stimuli appearance was the same. In Condition 2, the priming is given by the trials. As a new background image appears, the subjects have to look for a possible target. In Condition 3, the priming was removed in order to put the subjects in a situation closer to a driving situation. 150 stimuli (30 presentations for Contrast 0, 43 presentations for Contrast 0.3, 36 presentations for Contrast 1.2 and 41 presentations for Contrast 4.8) were presented to each participant, both in Conditions 2 and 3. Square targets were inserted in the images and video using a dedicated software developed at the LEPSIS. The target position was randomly chosen, with the restriction that it was situated on a homogeneous portion of the road surface, which is consistent with the STV reference scenario. Moreover, no target appeared during turnings at crossings. The luminance was computed on each image using the photometric calibration of the display device, allowing to predict the displayed contrast. Thus, the contrast with the near background in the displayed images and video could be set to either 0, 0.3, 1.2 or 4.8, as in Condition 1 (see Fig. 4). The variable number of stimuli per contrast value is due to the software, which randomly selected one contrast among the four values when adding a target in the images.

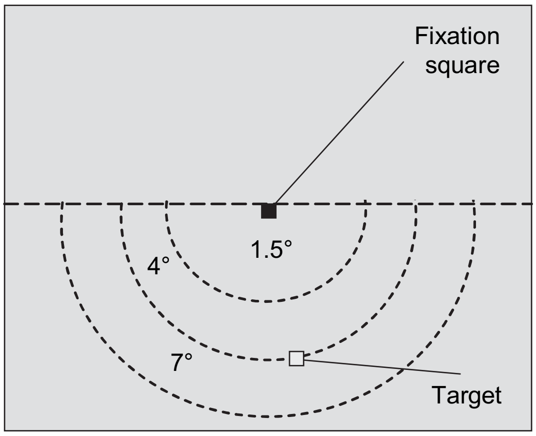

Fig. 3. Example of a stimulus with an eccentricity of 4° in Condition 1.

In Condition 3, the stimuli did not move, while everything else moved. Thus, the detection performance may have been slightly improved, because optic flow indexes may have highlighted the targets. However, due to the short presentation time (230 ms), we assumed that the effect (if any) was probably low.

2.5. Experimental design

2.5.1. Variables

The first independent variable was the *Condition*: Uniform background in Condition 1, still road images in Condition 2, and video in Condition 3. The second independent variable was the *luminance contrast* of the targets, defined as the Weber fraction $C = (L_t - L_b)/L_b$, where L_t is the target luminance and L_b the background luminance. An exploratory experiment suggested that contrasts ranging from 0 to 5 could produce a detection rate of 100% for the 3 Contrasts and for the 3 Eccentricities in Condition 1. Four contrast values were used in this experiment (0; 0.3; 1.2; 4.8), in the 3 Conditions.

For the three Conditions, the eccentricities were computed from the eye tracker data and used as a covariate in the data treatment. In Condition 1, the data allowed to control whether the gaze fixation was on the fixation square or not during target presentation. In

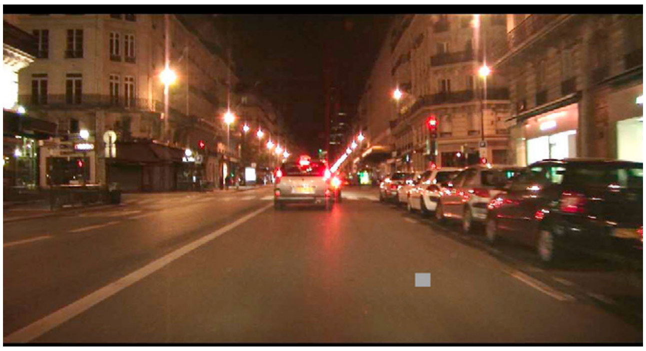

Fig. 4. Example of an image with a target. The target size and luminance contrast are not realistic.

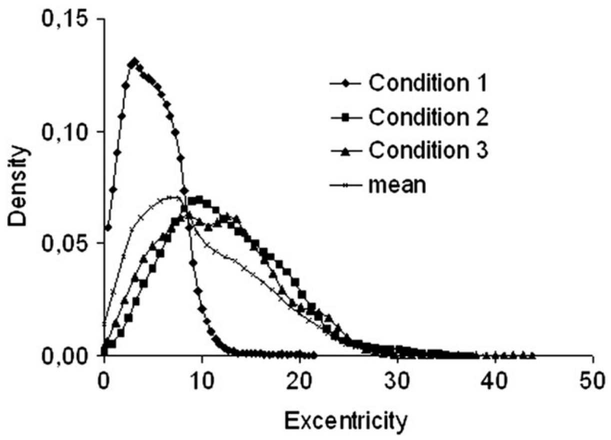

Fig. 5. Probability density of the eccentricity at the moment of target detection: comparison of Condition 1, 2, and 3.

Table 1
Effects on the detection performance.

Factors	*Chi*^{2}-value	*P*-value
Condition	208.90	0.000
Contrast	43.89	0.000
Eccentricity	3.30	0.069
Group	9.36	0.096
Gender	1.14	0.285
Acuity	41.21	0.000
Age	1.77	0.184
Condition × Contrast	14.13	0.007
Condition × Eccentricity	6.67	0.036
Condition × Acuity	10.43	0.005
Contrast × Eccentricity	17.71	0.000

Conditions 2 and 3, the subjects could freely explore the visual scene.

During the experiment, a computer recorded the task performance (number of correct and wrong answers) from the pedal responses. Correct answers were defined as answers occurring with a Reaction Time (RT) lower than 1.5 s after stimulus presentation.

2.5.2. *Procedure*

All participants passed a visual acuity test (Visiotest). A corrected binocular visual acuity of 5/10 was required to participate in the experiment, and all subjects had at least 8/10 corrected binocular acuity. Subjects wore the optical correction that they normally wear while driving, if any. They sat at a distance of 2.75 m from the screen, one foot on the pedal in order to report target detection. After a 8-min adaptation period to the mesopic illumination (0.65 cd/m^2 on the display screen), the eye-tracking system was calibrated.

In Condition 1, the subjects were instructed to stare at the fixation square and to press the pedal as soon as they detected a stimulus. In Condition 2, the instructions were the same as in Condition 1, except that they could freely explore the images (no fixation square), and that they were informed that the targets were to appear on the road surface. In Condition 3, in order to make the task more realistic, a steering wheel was provided and the participants were asked to mimic the steering behaviour with the steering wheel. This low demanding task was their priority task, however no lever gear or gas/brake pedal was available. In all Conditions, participants were instructed to respond as quickly as possible with the response pedal.

The three Conditions lasted about 1 h altogether per participant: about 10 min in Condition 1, 15 min in Condition 2, and 20 min in Condition 3. A short rest was proposed in the experimental room and a re-calibration of the eye tracker was done between the Conditions.

2.6. *Statistical analysis*

The data from four participants had to be removed from the analysis because of technical failures of the eye-tracking system, resulting in too many missing eye fixation data. Thus, data from 28 adults (8 women and 20 men) with a mean age of 39.9 years old ($SD = 11.8$) were analysed. No statistical difference was observed between the 6 counterbalanced groups in terms of age ($F(5, 22) = 1.17$, $p = 0.350$). Fig. 5 shows that the eccentricity distribution of the targets in Condition 1 (fixation square) was different from those in Conditions 2 and 3 (free viewing). The eccentricity was thus included as a covariate in the statistical model.

Detection performance were analysed with a logistic model by clustering over subjects with the Group and Gender as between-subject factors, Contrast and Condition as within-subject factors (Group (6) × Gender (2) × Contrast (3) × Condition (3)), and Acuity, Age and Eccentricity factors as covariate. The statistical significance level was set to 0.05. As the “detection” of a target with null contrast corresponds to a false detection, the null contrast data were not included in the logistic model. An analysis based on the Signal Detection Theory was also done (Wickens and Holland, 2000), in order to test the change in sensitivity and criterion shift with Condition.

3. Results

Table 1 shows the factor effects on detection performance. The logistic model computed on the detection rate indicated that the Acuity factor ($\chi^2(1) = 0.21$, $p < 0.001$) was statistically significant, whereas the Group factor ($\chi^2(5) = 9.36$, $p = 0.096$), the Gender factor ($\chi^2(1) = 1.14$, $p = 0.285$) and the Age factor ($\chi^2(1) = 1.17$, $p = 0.184$) weren't statistically significant.

The Condition effect, $\chi^2(2) = 208.90$, $p < 0.001$, was statistically significant. On the average, the mean detection rate decreased from 99% in Condition 1–81% and 37% in Condition 2 and 3, respectively. The logistic model also indicated that the Contrast effect ($\chi^2(2) = 43.89$, $p < 0.001$) was statistically significant. The mean detection rate increased from 52% for Contrast 0.3–79% for Contrast 1.2, and 86% for Contrast 4.8 (Fig. 6, left). Furthermore, the interaction between the Condition and the Contrast factors ($\chi^2(4) = 14.13$, $p = 0.007$) was statistically significant (Fig. 6, right): the Condition effect lowers when the Contrast increases.

The simple effect analyses of Conditions for Contrasts 0.3 ($\chi^2(2) = 223.80$, $p < 0.001$), 1.2 ($\chi^2(2) = 147.28$, $p < 0.001$) and 4.8 ($\chi^2(2) = 119.24$, $p < 0.001$), were all statistically significant. For Contrast 0.3, the mean detection performance was 98%, 58% and 7.8% in Conditions 1, 2 and 3 respectively. The *post hoc* pairwise comparisons indicated that the difference between Conditions 1 and 2 ($\chi^2(1) = 16.48$, $p < 0.001$), Conditions 2 and 3 ($\chi^2(1) = 111.34$, $p < 0.001$), and Conditions 1 and 3 ($\chi^2(1) = 162.04$, $p < 0.001$), were all statistically significant. For Contrast 1.2, the mean detection performance was 99%, 92% and 46% in Conditions 1, 2 and 3 respectively. The difference between Conditions 1 and 2 ($\chi^2(1) = 4.79$, $p = 0.029$), Conditions 2 and 3 ($\chi^2(1) = 0.84$, $p < 0.001$), and Conditions 1 and 3 ($\chi^2(1) = 67.46$, $p < 0.001$) were all statistically significant. For Contrast 4.8, the mean detection performance was 99%, 95% and 62% in Conditions 1, 2 and 3 respectively. The difference between Conditions 1 and 2 ($\chi^2(1) = 0.005$, $p = 0.946$) was not statistically significant. Between Conditions 2 and 3 ($\chi^2(1) = 100.50$, $p < 0.001$),

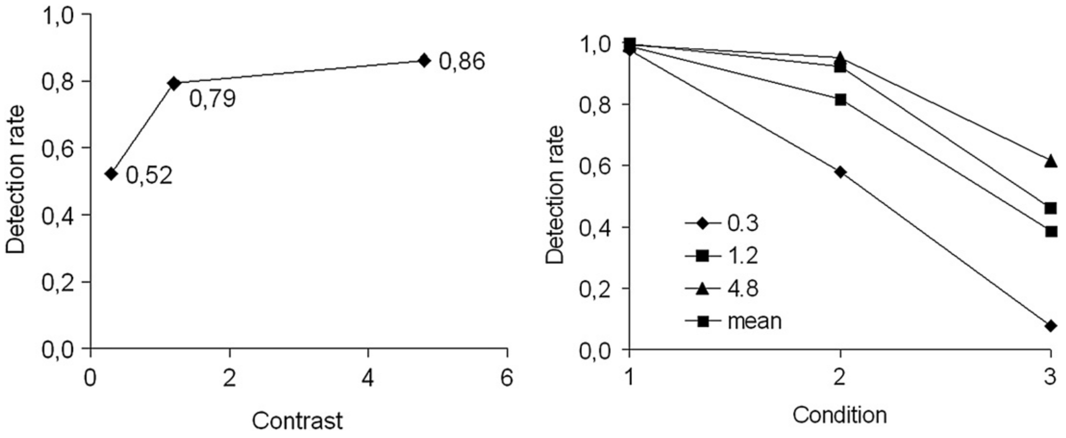

Fig. 6. Mean performance value (correct detection rate) for the three Contrasts (left) and interaction between the three Contrasts and the three Conditions (right).

and between Conditions 1 and 3 ($\chi^2(1) = 30.39$, $p < 0.001$), the difference was statistically significant.

The interaction between the Condition and the Eccentricity factors was statistically significant ($\chi^2(2) = 6.67$, $p = 0.036$). The simple effect analysis of Eccentricity in Condition 1 showed no statistical effect ($\chi^2(1) \approx 0$, $p = 0.098$). In Condition 2 ($\chi^2(1) = 41.63$, $p < 0.001$) and 3 ($\chi^2(1) = 27.28$, $p < 0.001$), the Eccentricity factor was statistically significant: The higher the eccentricity, the lower the detection performance. In order to compare the eccentricity effects between Conditions 2 and 3 (see Fig. 7), Condition 1 was removed from the data. An interaction was found between the Condition and Eccentricity factors in the remaining data ($\chi^2(1) = 4.71$, $p = 0.030$), showing that the eccentricity effect was stronger in Condition 2 than in Condition 3.

The interaction between the Condition and Contrast factors was statistically significant ($\chi^2(2) = 14.13$, $p = 0.007$). The simple effect analysis of eccentricity showed that the Condition effect was statistically significant for all three Contrasts, with $p < 0.001$.

The interaction between the Condition and Acuity factors was statistically significant ($\chi^2(2) = 10.43$, $p = 0.005$). A simple effect of Acuity was found in all 3 Conditions, with a regression parameter 0.72 in Condition 1 ($p < 0.001$), 0.61 in Condition 2 ($p < 0.001$) and 0.30 in Condition 3 ($p < 0.001$). Simple comparisons showed that the effect of Acuity was not statistically different between Conditions 1 and 2 ($p = 0.380$), but it was lower in Condition 3 than in Conditions 1 ($p = 0.005$) and 2 ($p = 0.004$).

The interaction between the Contrast and Eccentricity factors was statistically significant ($\chi^2(2) = 17.71$, $p < 0.001$). The simple effect analysis of Eccentricity for Contrasts 0.3 ($\chi^2(1) = 7.26$, $p = 0.007$) and 4.8 ($\chi^2(1) = 4.25$, $p = 0.0392$) were significant, whereas it was not for Contrast 1.2 ($\chi^2(1) = 0.58$, $p = 0.044$).

The logistic model tries to predict the detection performance from binary data. The model was tested using a Receiver Operating Characteristic (ROC) curve, computing for threshold values between 0 and 1 the True Positive Rate against the False Positive Rate. We found a surface of 0.912 under the ROC curve, which denotes that the model is fairly predictive. The classical error rate $e = FP + FN$ (with FP = False Positives and FN = False Negative) is minimum for a detection threshold of 0.718, with a value $e = 0.317$ showing that whereas the data is not fully explained by the logistic model, the choice of a logistic model was correct.

In addition to this statistical analysis of the detection performance, the subjects sensitivity and response bias were analysed according to the Signal Detection Theory (Wickens and Holland, 2000). The sensitivity is the ability to discriminate between targets and noise, and depends both on the detection performance and on the false alarm rate. Using a generalized linear model with a probit link function, a Condition effect was found on the sensitivity, from 5.05 in Condition 1 to 3.30 in Condition 2 and 1.59 in Condition 3 ($p < 0.001$), which is consistent with the previous findings. The decrease in sensitivity means that adding context variables to the detection task lowers the subject's sensitivity. Interestingly,

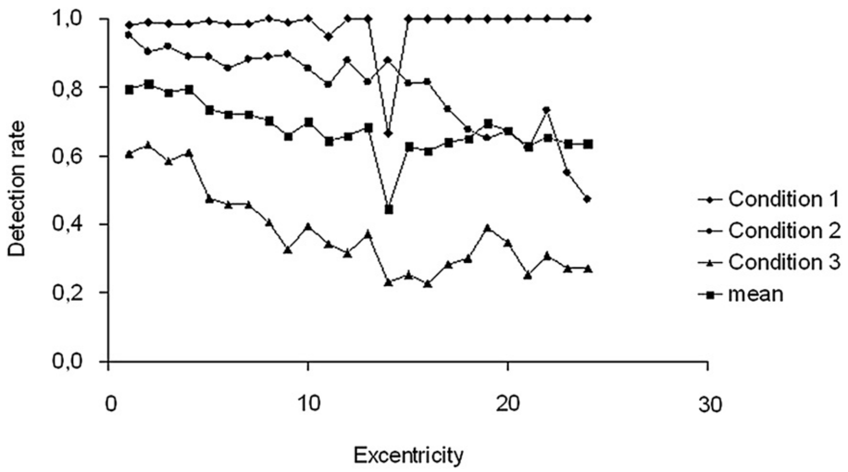

Fig. 7. Mean performance values (correct detection rate) according to the eccentricity in Conditions 1, 2 and 3.

a Condition effect was also found on the response bias, from 0.29 in Condition 1 to 0.77 in Condition 2 and 1.11 in Condition 3 ($p <$ 0.001), meaning that adding context variables to the detection task leads the subjects from a near neutral bias in Condition 1 to a more conservative bias with the video.

4. Discussion

The aim of this study was to evaluate whether the context (heterogeneous and informative background, apparent motion) would impact the target detection performance in peripheral vision. We used an experimental design with 3 Conditions. Condition 1 was chosen close to the psychophysical protocol used in the STV reference data. In Conditions 2 and 3, two factors were added: the spatial context, and the apparent motion (video flux). Luminance levels were chosen in the mesopic domain relevant for road lighting applications. Images and video were chosen in relation to a driving task at night.

The results showed that both the spatial context and the apparent motion have a negative impact on the peripheral target detection performance. Effects of contrast and eccentricity are found in a way consistent with common psychophysical knowledge. All 3 contrast values allowed, as expected, a high detection rate in Condition 1. However, contrasts which are easy to detect on a uniform background may lead to poor performance if one adds context variables.

The addition of a visual context may, theoretically, lead to several kinds of biases. The spatial heterogeneity of the background image tends to decrease the target detection performance (e.g. Paulmier et al., 2001), which may also be expressed in terms of distractors, or in terms of visual masking (Legge and Foley, 1980). However, introducing the semantic structure in the scene allows the observers to make some expectations about relevant items, which are then easier to detect. Our findings show that this facilitation effect is weaker than the visual masking effect. One possible explanation is that the conventional square target used in road lighting design cannot be thought to as a “relevant item” in a driving context, so that expectations due to the informative background (road scene) are low. This result gives road engineers new motivations to move from the conventional square target to a more realistic one, although the choice of a broadly accepted new reference target may be a complicated issue.

The proposed framework allowed to control the effects of various factors related to the driving task on target detection performance at night. A first experiment showed that the peripheral detection and task load are among the relevant factors of night driving which are not taken into account in the STV model (Mayeur et al., 2008). These results are strengthened in the present study, where evidence is given that context information such as road background and apparent motion also lower the target detection performance. Together, these results show effects of four important factors on target detection performance, all in the same direction (lowering the performance when the factor is taken into account) and emphasize the weaknesses of the STV model used for road lighting design.

Gathering these findings leads to a multi-component approach of the “field factor”. This factor is used by practitioners to compensate for the difference between the STV reference scenario (detection of a small target on a lit road while driving) and the psychophysical reference data. Even if all relevant factors have not been studied so far (e.g. the possible effect of ongoing traffic was not considered, nor the target shape and size), our multi-component approach already showed that the driving activity, the target eccentricity, the spatial, semantic and dynamic context are among the factors which have a significant impact on target detection. The point is not to guess which factor has the stronger effect on detection performance. Moreover, there is no *a priori* reason why the relative weight of these factors may be the same in all driving situation. Conversely, we propose to use several “field sub-factors”, which would be combined for lighting design. The importance of each of these sub-factors would depend on the road environment and usage, so that a global field factor could be computed from the road categorization. For instance, the eccentricity effect may be more important in urban areas than in motorways, as relevant information is more sparse in the visual field; the motion effect may depend on the vehicle speed; and so on. Note that the proposed approach does not consider the interactions between sub-factors.

Consequently, future research includes building a new road network classification. Actual classifications, such as the road network classification in the recent European Norm (2005), stands on a road description in terms of traffic, while other categorizations stand on the driver’s expectations (Mazet and Dubois, 1988). In our view, a road section classification based on the importance of the visibility sub-factor (eccentricity range, visual complexity, task load, speed, etc.) would deserve a more relevant road lighting design.

Field experiments would enforce the present findings, as it would gather all the factors which are separated here. Therefore, we have conducted a field experiment on a closed circuit, which confirmed that the driving activity, even with a low demand on information processing and a low demand on vehicle handling, has an effect of peripheral detection (Mayeur et al., Submitted for publication). Driver and Passenger status were compared, and 16 Visibility Levels (VL) were used for the same flat square target as in the STV model. In the Driver status, 34 participants had to press a button as soon as they detected the target stimulus placed on the experimental road. In the Passenger status, the same participants had to detect the target while the experimenter drove. The main result was that it is easier to detect targets when the subject is a passenger than when s/he is driving. These results strengthen the findings of laboratory experiments (Brémond and Deugnier, 2006; Mayeur et al., 2008), showing that the passengers and drivers visual performance are different and that the driving situation impacts target detection performance.

Future research includes the understanding of more factors on road visibility. The impact of the traffic and the environment complexity are among the more obvious. We have seen that the target choice also needs a specific discussion, which may lead to more changes in the STV reference data and reference scenario altogether.

Collaborations with practitioners would be beneficial in order to build an alternative quantitative model based on our findings. We hope that our approach may contribute to a modified model of road visibility at night, by proposing a methodology in order to modulate the field factor of the STV model, which could take into account the main components investigated in our experiments.

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Anaïs Mayeur is pursuing a PhD in ergonomics at the Paris Descartes University (Paris, France). She got a Master in Ergonomics from the Paris Descartes University in 2007. Her current researches focus on vision and driving and road lighting design.

Roland Bremond is researcher at the University Paris Est (France) since 1996. He had his engineer degree from the ENPC in Paris in 1990 and his PhD from the ENSMP in 1993 in the field of image processing. His current researches focus on human vision for road safety applications, including road lighting, driving simulation and computer graphics.

J.M. Christian Bastien got his PhD in 1996 in Cognitive Ergonomics from René Descartes (Paris 5, France) University where he has been affiliated since 1998. Christian Bastien is now affiliated to Paul-Verlaine University in Metz (France) where he continues his research in usability methods and cognitive ergonomics.