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Discomfort glare in motion

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Abstract — This study investigates the relation between static and dynamic discomfort glare, as experienced by drivers, in a laboratory experiment with a panel of 32 participants. It provides a model to estimate an overall glare level from successive static glare levels. This model integrates a temporal decay of the glare level memory.

Keywords—Discomfort glare, automotive lighting

I. INTRODUCTION

Currently, discomfort glare ratings are collected in static positions, and most models compute a De Boer score from photometric and geometric characteristics based on these static data [1, 2]. But road users are moving with respect to the glare sources (e.g. headlamps of traffic in the opposite lane, or streetlamps along the road), which creates some ambiguity regarding the reference position, and regarding the possible effect of the driver ego-motion [3].

When the driver passes a single oncoming car, he may feel discomfort from transient glare. Previous studies show that the duration of the exposure to glare has an effect on the discomfort. Sivak et al. found with real headlamps that the discomfort increases when the duration of the glare increases from 0.125 to 2 s [4]. Lehnert found similar results between 0.2 s and 10 s [5]. According to Ahmed and Bennett's work, less discomfort from glare is felt for durations below 0.2 s than for longer time lapses; the discomfort from glare is almost constant between 0.5 and 5 s, and decreases slowly between 5 and 10 s [6].

Sivak and Olson proposed a methodology to assess the discomfort from glare caused by car headlamps briefly switched on [7]. Participants were asked to drive on a straight road at constant speed (50 or 100 km/h). Another car was stopped on the opposite lane; its headlamps were switched on and off when a participant's car arrived at two specific locations. Discomfort was assessed after each exposure on the De Boer nine-point scale: it was slightly higher at 100 km/h, but the difference was not significant.

Reagan et al. investigated the discomfort from glare due to various headlamps on a closed track [8]. Twenty participants were asked to observe a test vehicle approaching along a straight road, a sharp left or right curve, or a soft left or right curve. They had to assess the discomfort from glare on a De Boer scale. The goal of the study was to compare fixed halogen, fixed HID, and adaptive HID low beam headlamps. The illuminance at the eye of the observer was recorded during the last 50 m of the test vehicle approach. Mean glare level and mean illuminance gave the same ranking for the headlamps, but the correlation between illuminance measurements and subjective glare ratings was not investigated.

Focusing on street lighting, Van Bommel described the continuous glare variation experienced by a road user during his motion along the street as a dynamic pulsating glare effect

[9]. To investigate such dynamic aspects of glare, Bennett et al. developed a driving simulator [10]. With this tool, Liu and Konz found no influence of the speed (comparing 65 and 95 km/h) on the overall discomfort glare perceived under a street lighting installation [11]. More recently, Girard et al. investigated the impact of cyclic variations of the luminance, of the position and of the size of a light source on the discomfort from glare [3]. The results suggest that a periodic dynamic source is equivalent to a static source with the time-averaged values of luminance, eccentricity and solid angle.

Zhu et al. addressed discomfort from dynamic glare on an illuminated road with a laboratory experiment: LEDs were inserted in the diagonal of a screen, simulating luminaires on a street at night [12]. One or several LEDs were successively switched on to simulate the road user movement under road lighting, with three possible luminance amplitude levels (20%, 60%, 100% of the LED maximum). De Boer ratings were collected with 20 participants after each sequence, as well as fluctuations in the eye illuminance during each sequence. A significant effect of the maximum source luminance was found: the 20% condition was less glaring than the 60% and 100% conditions. Unfortunately, these data were not compared to a static glare condition.

Villa et al. investigated pedestrian's discomfort from glare on a closed track under four different urban lanterns with 33 participants [13]. Mean ratings after walking under each installation were lower than the average of four ratings given from static positions along the same path. These findings highlight the need for further researches (as stated in [9]) to understand the dynamic glare effect.

In this context, we have studied to what extent static glare models can be relevant to explain subjective judgments on dynamic glare assessments. In this study, we focused on automotive lighting. To that purpose, the relation between static discomfort glare and dynamic discomfort glare due to automotive lighting was investigated with a laboratory experiment.

II. MATERIAL AND METHODS

A. Panel

Thirty-two participants were involved in this study (16 men, 16 women), aged between 19 and 61 years ($M=35.25$, $SD=11.13$). With their usual ocular corrections (glasses or lenses) if any, all participants had a visual acuity above 6/10 ($>5/10$ is required in French traffic regulations). They were employees of the university and were naive to the purposes of the experiments. Before the experiment, they received instructions and signed an informed consent form.

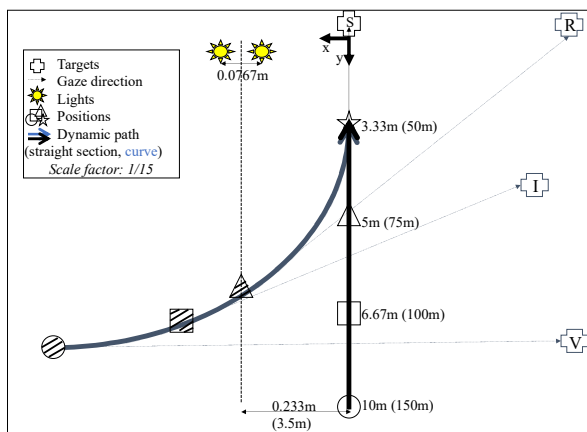


Fig. 1. Geometry of the experimental settings.



Fig. 2. Photographs of the experimental setup.

TABLE I. CHARACTERISTICS OF THE LEFT AND RIGHT SOURCES FOR EACH POSITION: ECCENTRICITY, SOLID ANGLE AND SOURCE LUMINANCE

<i>position</i>	θ (°)		ω (sr)		L_s (cd/m ²)	
	Left	Right	Left	Right	Left	Right
Stripped circle	44,7	44,0	$2 \cdot 10^{-6}$	$2 \cdot 10^{-6}$	$1 \cdot 10^5$	$1 \cdot 10^5$
Stripped rectangle	28,4	27,5	$2,7 \cdot 10^{-6}$	$2,6 \cdot 10^{-6}$	$9,9 \cdot 10^4$	$9,8 \cdot 10^4$
Stripped triangle	18,1	17,1	$4,1 \cdot 10^{-6}$	$4,1 \cdot 10^{-6}$	$2,7 \cdot 10^5$	$2,7 \cdot 10^5$
Star	4,8	3,4	$7 \cdot 10^{-6}$	$7 \cdot 10^{-6}$	$1,8 \cdot 10^5$	$4,5 \cdot 10^5$
White triangle	3,2	2,3	$3,1 \cdot 10^{-6}$	$3,1 \cdot 10^{-6}$	$2,5 \cdot 10^5$	$3,9 \cdot 10^5$
White rectangle	2,4	1,7	$1,8 \cdot 10^{-6}$	$1,8 \cdot 10^{-6}$	$2,9 \cdot 10^5$	$3,8 \cdot 10^5$
White circle	1,6	1,1	$7,8 \cdot 10^{-7}$	$7,9 \cdot 10^{-7}$	$2,9 \cdot 10^5$	$3,7 \cdot 10^5$

B. Experimental setup

Two simple typical driving situations where drivers may feel discomfort from the headlamps of oncoming traffic were simulated in the laboratory: a straight section and a left curve. LED lamps were used to simulate the headlamps of an oncoming vehicle: a car (two lamps) and a motorcycle (left lamp). The experimental setup is provided in Fig. 1 and illustrated in Fig. 2. The spatial dimensions corresponded to a scale factor of 1:15 with respect to real-world distances. The vertical position of the lamps was tuned to the height of every participants, so that they were always at the same vertical position with respect to the eyes.

The straight section and the curve were sampled with four positions (marked as circles, rectangles, triangles, and a star in Fig. 1). Characteristics of the glare sources as seen from each position are provided in Tab I. The luminance values were

calculated from vertical illuminance measurements (LMT B520 luxmeter) at each position. Luminaires at the ceiling of the experimental room were dimmed to produce a background luminance ranging between 0,3 and 0,9 cd/m² depending on the position (M=0,60 cd/m², SD=0,25).

C. Experimental protocol & design

The participants were asked to pretend they were in the context of driving, to stand at the four different positions (circles, rectangles, triangles, star, see Fig. 1), to direct their gaze towards the different targets, and to rate the discomfort they experienced from the lamp(s) in each case, using a De Boer scale they carried on a paper sheet. In addition to these 7 static conditions, dynamic experimental conditions were added where the participants were asked to look at successive target(s) (shown in Fig. 1 and 2) while walking along the straight line or along the curve, and then to rate the overall discomfort they had experienced during this motion, on the same De Boer scale. Four dynamic ratings were collected for each participant:

- LINE 1: Participants walked from the white circle to the star, with their gaze on target S; one light was on;
- LINE 2: They walked as in LINE 1; two lights were on;
- CURVE 1: They walked along the curve formed by the striped symbols up to the white star, with their gaze moving along from target V to target S [V→I→R→S]; one light was on;
- CURVE 2: They walked as in CURVE 1; two lights were on.

Half of the participants started with one light source on, the other half with two light sources on. For each situation, static and dynamic conditions were assessed in balanced and random order. For the static conditions, the order of the positions was random. The order of the two paths for the dynamic condition was balanced among participants.

III. RESULTS

A. Ratings

First, a cluster analysis was carried out. No outliers nor groups were identified from the hierarchical clustering analysis (conducted with the percent disagreement distance and average linkage). Therefore, all the data were included in further statistical analyses.

Fig. 3 presents the mean rating values on the De Boer scale for each static position and the mean overall dynamic rating values for both paths (line and curve), as well as the 95% confidence intervals (CI95%). The CI95% from the panel of 32 participants ranged between 0,7 and 1,5 level on the De Boer scale, depending on the experimental condition.

As expected, the static discomfort from glare is higher in both the straight line and the curve (lower ratings on the De Boer scale) when the observers are closer to the source(s).

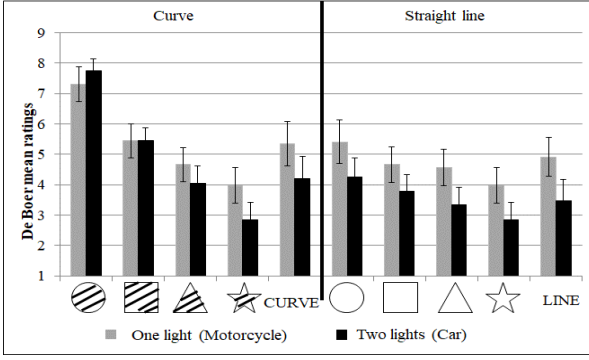


Fig. 3. Mean de Boer ratings in static and dynamic conditions, and 95% confidence intervals.

B. Relation between static and dynamic ratings of discomfort from glare

A statistical analysis helped computing a rough estimate of the dynamic ratings from the static ratings. Then, based on this first estimate, a mathematical approach was carried out to propose a model predicting the dynamic rating from the successive static ratings.

a) Comparison of the distributions of static and dynamic ratings

In order to investigate a possible link between static and dynamic ratings, a Wilcoxon-paired test was employed. For each path (line / curve) and each condition (one lamp / two lamps), the distribution of the dynamic ratings was compared to the distribution of the static ratings, for several features: the position, the subject's mean, minimum and maximum ratings, and a weighted sum of the mean static ratings R :

$$1/10 R_{\text{circle}} + 2/10 R_{\text{rectangle}} + 3/10 R_{\text{triangle}} + 4/10 R_{\text{star}} \quad (1)$$

This idea was proposed based on two hypotheses:

1. The overall discomfort from glare along a path is a weighted sum of the static discomfort at each position along the path;
2. The more recent stimuli have more importance in the global rating than the older ones.

The second hypothesis is in line with the “recency effect” in cognitive psychology [14], which states that recent stimuli are easier to recall than older stimuli. A theoretical framework has been proposed for attentional capture to take the recent history into account in order to predict attentional selection [15], with more weight on recent events. We extend this approach to another field of psychophysics, discomfort glare.

The results are provided in Tab. II: those static distributions which are not significantly different from the dynamic distribution are in bold. The distribution of static ratings of the third position (triangle) and the weighted sum distribution are never significantly different from the dynamic one. These results suggest a temporal influence of the path. Moreover, the three last positions in the path have more influence on the *a posteriori* dynamic judgment than the first one in both the straight and the curved path, with more weight associated to the last positions.

TABLE II. COMPARISON OF STATIC AND DYNAMIC DISTRIBUTIONS: WILCOXON-PAIRED TEST RESULTS (P-VALUE)

	LINE 1	LINE 2	CURVE 1	CURVE 2
Circle	0,223	0,034	<0,001	<0,001
Rectangle	0,390	0,247	0,794	0,001
Triangle	0,330	0,615	0,063	0,509
Star	0,0086	0,012	<0,001	0,002
Max	0,070	0,001	<0,001	<0,001
Mean	0,325	0,813	0,746	0,008
Min	0,003	0,001	<0,001	<0,001
Weighted sum	0,064	0,421	0,077	0,845

b) A model of dynamic glare rating from successive static glare ratings:

Along the path, one can sample a succession of static positions for which a static De Boer rating can be provided from a static model (e.g [1]). Based on the previous findings, we assessed whether the overall dynamic rating M_{dyn} could be predicted from a function of the static ratings $M_{\text{static}}(t)$, such as:

$$M_{\text{dyn}} = \int_{-t_h}^0 \rho(t) M_{\text{static}}(t) dt \quad (2)$$

where $\rho(t)$ is a linear weighting function, expressed as:

$$\rho(t) = \frac{2}{t_h^2} t + \frac{2}{t_h} \quad (3)$$

which leads to:

$$\int_{-t_h}^0 \rho(t) dt = 1 \quad (4)$$

The weighting function $\rho(t)$ simulates the fading importance of past glare, assigning higher weights to the near past (see Fig. 4). The parameter t_h represents the time span (in seconds) which impacts the ratings. The value $t_h = 3,5$ s was tuned to the experimental data; it is expected that the glare experience more than t_h seconds before present does not affect the current judgment (this is a strong hypothesis but it may be acceptable in a road context).

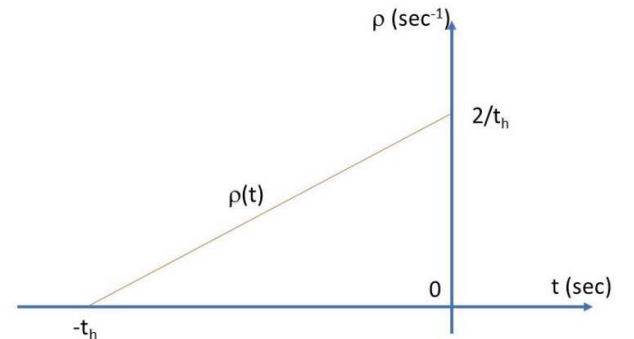


Fig. 4. Proposed weighting function for the estimation of the dynamic glare rating from static glare ratings.

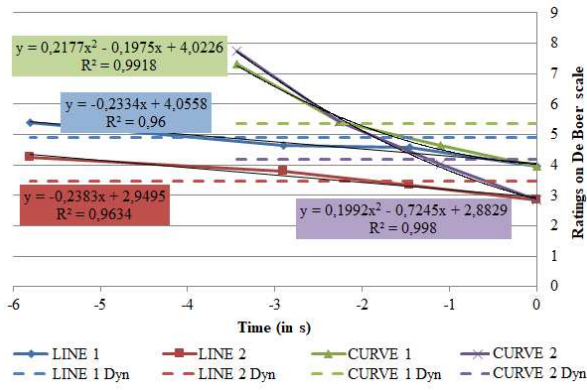


Fig. 5. Functions $M_{static}(t)$ fitted on the mean observed static ratings (continuous lines) and observed mean dynamic subject ratings R_{dyn} (dashed lines).

TABLE III. DYNAMIC MODEL PREDICTIONS M_{dyn} FROM $M_{static}(t)$ AND COMPARISONS TO THE MEAN DYNAMIC SUBJECT RATING R_{dyn}

	LINE 1	LINE 2	CURVE 1	CURVE 2
M_{dyn} predicted from $M_{static}(t)$	4,33	3,23	4,70	4,14
Mean Dynamic rating R_{dyn}	4,91	3,47	5,34	4,19
C195%	0,64	0,69	0,73	0,74
Difference Model – Subjects	-0,58	-0,24	-0,64	-0,05

Based on the timing of two persons, we have assumed that the subjects were walking at 1,15 m/s in the straight line and 1 m/s in the curve. Then, the static ratings of the sampling of the straight path and of the curve path were plotted as a function of time (see Fig. 5). Regression was employed to interpolate the $M_{static}(t)$ function for each path and condition. Their equations are provided in Fig. 5. Mean dynamic ratings are also plotted in Fig. 5 in dotted lines.

The M_{dyn} predicted by the proposed model (2) from the $M_{static}(t)$ values are provided in Tab. III. The difference between the predictions and the mean dynamic ratings are lower than 0,6 levels on the De Boer scale, which is lower than the 95% uncertainty on the mean dynamic ratings.

This result means that for the tested configurations, a weighted sum of the static discomfort glare ratings collected during the 3,5s before the end of the path can predict the global dynamic discomfort glare rating.

IV. DISCUSSION

In this work, based on subjective data collected in an experimental set-up in the lab, we proposed a model to predict the overall dynamic glare level from successive static glare levels, for a moving observer. This model assumes that the glare experience fades away with time. It could be implemented with a static glare model to estimate dynamic glare levels.

The mathematical formulation of the proposed model allows using any static model of the discomfort from glare, for instance Schmidt Clausen and Bindel's model (M_{SCB}) [1] and

computing a dynamic discomfort glare level at time t_0 from the static computations between t_0-t_h and t_0 :

$$M_{dyn}(t_0) = \int_{t_0-t_h}^{t_0} \rho(t) M_{SCB}(t) dt$$

Considering the scale factor of the experimental set-up, the experiment corresponded to a driving speed of around 54-62 km/h. Slower and higher speeds need to be investigated to ensure that the proposed model is relevant in different driving conditions. In addition, further investigations are required to assess the validity of the model and of the t_h parameter value for other paths with various speeds, durations and sources.

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