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STIMULUS RANGE EFFECT IN DISCOMFORT GLARE STUDIES

Roland Brémond

roland.bremond@univ-eiffel.fr

Université Gustave Eiffel, Département CoSys, laboratoire PICS-L

14-20 Bd Newton, 77440 Champs sur Marne, France

Abstract (118 words): *When asked for a subjective judgment, such as rating the discomfort from a glare source, the response of participants depends on the range of stimuli they are provided: this is known as a stimulus range effect. In the present note, the stimulus range effect is discussed in the context of discomfort glare studies. Its status is compared to various kinds of biases, in the metrological and in various psychological senses. This discussion leads to discard the idea that the stimulus range effect should be considered a bias in the case of discomfort glare. A methodology (stimulus range selection) is described to overcome the stimulus range effect problem in the modelling of discomfort glare, at least for engineering applications.*

Keywords: *stimulus range effect; discomfort glare; psychophysics; methodology.*

It has been clear since the beginning of the 20th century that glare impacts us in various ways: it may produce discomfort, impair visual performance, and cause physiological damages to the eye [1,2]. Specifically, discomfort glare has been described as the subjective consequence of glare. A number of psychophysical studies have been conducted in order to model this discomfort from photometric and geometric parameters, under natural [3] and artificial light, indoor [4,5] and outdoor [6-8]. This effort led to several CIE reports [9-13], but no consensus has been reached so far towards a unified model. Report CIE 205 [14] suggests exploring image processing techniques: the CIE TC 3-57 follows this path [15].

The lack of a unified model is due to two main reasons. First, a model is a simplified account of the real world, and the appropriate simplifications are not the same in indoor and outdoor lighting, in artificial and natural lighting. For instance, existing models of discomfort glare due to outdoor lighting use to consider uniform light sources standing on uniform backgrounds, in static settings. This may be considered as a useful trade-off to build a model, but cannot generalize to all situations, with heterogeneous light sources [12], complex background luminance, sometimes moving light sources [16] and moving gaze [17].

Another reason for the differences across models comes from methodological issues in the psychophysical experiments, which allowed building these models [18]. The present paper focuses on one of them, the “stimulus range effect”. I first describe the concept of stimulus range effect in psychophysics and its meaning in discomfort glare experiments, and explain why it raises a problem when building a unified model of discomfort glare.

As the stimulus range effect is sometimes described as a bias, I also discuss the notion of experimental bias, in the metrological and in various psychological senses. This allows discarding the idea that the stimulus range effect can be considered a bias in the case of discomfort glare. Finally, a methodology is described to overcome the range effect problem in the modelling of discomfort glare.

The psychophysics of discomfort glare

Most studies on discomfort glare, both for indoor and outdoor applications, have been conducted in the lab, where various glaring stimuli are presented to panels of observers. These are psychophysical studies, and as such, they are expected to follow the guidelines of experimental psychology [19]. An experiment is described with its *Independent Variables* (IV), or experimental factors, which vary from stimulus to stimulus (for instance, the source luminance, its position), and its *Dependent Variable* (DV), which is the output of the experiment (for instance, a discomfort level on a scale). The DV is derived from the participants' responses, while the IV are manipulated by the experimenter.

The data collected in a psychophysical experiment constitute a dataset which is summarized in an equation (the model) where the DV is a function of the IVs. Discomfort glare models include two parts: first, a glare formula computes the Glare Excitation (GE) from the visual environment (background and sources luminance, size and position, etc.). Then, the model computes the discomfort level from the GE, as expressed on a discomfort scale (some models, such as the VCP, compute the percentage of people feeling uncomfortable instead of a discomfort level). Two main types of DV have been used in previous discomfort glare studies: rating scales, such as the de Boer scale [7], and thresholds, such as the BCD, the Borderline between Comfort and Discomfort [4].

Whatever the choice of the IVs and DV, context effects are present in all experimental situations. This expression, “context effect”, refers to the fact that while the experimenter is only interested in the effect of the IVs on the DV, other (unwanted) factors also have an effect on the DV, that is, modulate the participant’s response. Some of these unwanted factors depend on individual characteristics (e.g. fatigue, eye pigmentation), some depend on the experimental protocol itself [20-21]. It is a general problem in psychophysics, and the stimulus range effect is probably the most famous among these unwanted factors.

The stimulus range effect

In an experiment on discomfort glare, the participants tend to report more or less discomfort when looking at a given glaring stimulus, depending on the range of stimuli displayed in the whole experiment (and possibly in pre-tests [22]). This effect does not change the GE formula, but it may change the discomfort level associated to a given stimulus.

The stimulus range effect was described by Parducci in a series of publications showing that the range of the displayed stimuli may impact the response of participants in a psychophysical experiments collecting judgments [20, 23-26]. His approach was to include the stimulus range as an experimental factor (an IV) allowing predicting the DV, leading to his range-frequency model.

Parducci focused on relative judgments, using words such as “large”, “small”, “interesting”: he deliberately avoided anchoring the participants’ responses with expressions such as “small as a 1\$ coin”. Thus, participants tended to answer in reference to the range of displayed stimuli. Lulla & Bennett followed this approach to estimate the discomfort glare, and obtained similar results [27]. Before the experiment, they insisted that the BCD was somewhere inside the range of the stimuli that would be displayed; and indeed, the participants found the BCD somewhere inside this range, at a higher luminance level when the luminance range was broader.

So one reason why a stimulus range effect can be found is that the experimenter indirectly suggests that the “right” answer needs that the participant take the whole range of stimuli into account. In such protocols, the experimenter suggests that the range of available stimuli should be considered as a reference range against which the judgments are given. Semantic anchors mitigate this effect [28]: the words used by the experimenters in their verbal instructions, such as “discomfort” or “unbearable” refer to a subjective experience that a participant is able to feel and report, independently of the context. Still, words are not absolute references, and even with these anchors, stimulus range effects have been found.

The problem

For lighting engineers, the purpose of discomfort glare models is to tune lighting installations in such a way that people are not too disturbed by the lighting. They need a threshold value above which the lighting installation is too uncomfortable in a given setting (office, road, etc.), or above which too many people feel uncomfortable. But the stimulus range effect states that considering the same panel and the same experimental protocol, two models based on data collected with two different ranges of glaring stimuli lead to two different predictions of the discomfort level [27].

This is why some authors recommend not to use the absolute values predicted by these models, but rather to limit their use to stimuli comparisons [18]. The rationale is that the comparison of two stimuli (which one is the most disturbing?) only depends on the Glare Excitation, not on the discomfort level, so that the comparison is not impacted by the range effect. The CIE TC 3-57 follows this path: its goal is to propose a model of the glare excitation based on the visual stimulus, not a model of the discomfort intensity. This approach is sound in terms of scientific consistency, but it is problematic for practitioners, who need some ideas of the threshold to use in real settings.

Effect vs Bias

Some studies, such as Parducci’s work and early papers from Poulton [29-31], have investigated the impact of the stimulus range as a “range effect”, while later papers from Poulton [21,32-33], considered it as a “range bias”. In the case of discomfort glare, some authors have also considered the stimulus range effect as a bias [34]. The two expressions are not equivalent. A “range effect” refers to the fact that the stimulus range affects the results, that is, the value of the DV. “Bias” is a metrological word: it refers to a systematic difference between the “true” value of a physical quantity, as measured with reference to metrological standards, and the

value measured with a biased measurement device (in psychophysics, a panel of participants is considered a measurement tool, and the “measurement” is the collection of their responses). For instance, you want to measure the length of some piece of wood, but your graduated scale is made of steel, and thus tends to dilate with temperature. There is a measurement bias: your scale does not give the right answer. In psychophysics, we may ask a panel of participants to estimate with the naked eye the length of a piece of wood, in meters. The mean response may be compared to the physical length of the piece of wood. If, for instance, people tend to underestimate this length, there is a bias in the sense that the panel of participants (considered as a measurement tool) gives a biased account of the physical length (as measured with a metrological standard).

However, most psychophysical experiments ask people for judgments that are not estimations of physical quantities. When asking people for their discomfort feeling, they refer to an internal, subjective feeling, not to an estimate of some physical property of the light source. In this case, there is no metrological standard of subjective feelings, no measurement device telling you what is in one’s head, except his own words. It is inappropriate to say people are wrong when they express their own subjective feeling, and the notion of metrological bias does not apply. It would mean that the experimenter knows the participants’ feelings better than they do.

Biases in psychology

Even if there is no such thing as a “physical measure of the feeling” or a “metrological standard of the feeling” which could serve as a reference (as it is required to deal with metrological biases), psychophysics belongs to experimental psychology, where various kinds of biases have been described in situations where no physical measure is available as a reference. An overview of these biases helps understanding whether the stimulus range effect in discomfort glare can be described as a bias in a psychological sense.

- It may happen that a participant does not tell the experimenter what he has in mind. For instance, the social-desirability bias refers to the fact that people tend to say what they think the experimenter wish them to say [35]. The reference, here, is the participant’s own judgment, and the bias is the gap between what he feels and what he says.
- The stimulus bias [36] concerns people who are asked about a perceptive judgment, and take a physical estimate into account in their answer. For instance, they are asked whether they feel an object is heavy, and they take its estimated weight into account in their answer. This bias can only be found when what Poulton names a “familiar unit” is available [21].

- Cognitive biases [37-38], together with the notion of limited rationality [39] refer to the fact that people are not always rational in their reasonings and judgments. In this context, a bias is a computational error, using the rational computation as the reference.
- Manipulating numbers is less easy for people than for computers; experimental psychology and neurosciences have investigated the way people use numbers [40]. Failures with numbers can be described as a bias, taking the arithmetical use of numbers as the reference. For instance, when rating stimulus A the double of stimulus B, it is expected that stimulus B should be rated half of stimulus A, but this does not always happen.

With some exceptions [27], the *social desirability bias* is not expected in discomfort glare studies, as it is difficult for a participant to guess that the experimenter expects something from him. No “familiar unit” is available for discomfort, which also discards the *stimulus bias*. As the judgment of discomfort does not result from a cognitive deliberation, Kahneman’s notion of *cognitive bias* may also be discarded. It may be that discomfort judgments are somehow affected by numbers representations when collected with numeric scales, but not with threshold estimations techniques (such as the luminance adjustment and paired comparisons) or non-numerical ordinal scales [41].

In some cases, a bias may also be defined with respect to a theoretical reference model. Poulton [21] followed Fechner [42] and considered there is only one psychophysical function for a given perceptive dimension (e.g. discomfort from glare), and that it can be derived from the Just Noticeable Differences (JND). He took this JND function as a reference, and described any departure from it as a bias. His notion of a “stimulus range bias” has been considered for discomfort glare [18]; it does not refer to a metrological bias, but to a theoretical hypothesis about a reference psychophysical model (the JND model). This “bias” is the gap between the JND model of the discomfort glare and any other model of the discomfort.

Poulton’s approach was proposed in the context of pure psychophysics, looking for general relationships between stimulus and response. He considered context effects as biases, focusing on the stimulus intensity as the IV. But his choice of the JND model as a gold reference was rejected by some important authors [43-44], and more importantly, in an engineering approach, context effects are not unwanted, they are real. More specifically, the stimulus range does affect the discomfort experienced on the road as well as in a classroom, because drivers and students have their own experience of previous stimuli, which affects their current feeling [45].

My view is that Poulton’s definition of the “stimulus range bias” is not relevant for discomfort glare studies if one wishes to predict the discomfort level in real situations. In the following, I show that selecting the stimulus range according to engineering needs may lead to more useful models of the discomfort level, at the cost of leaving the myth of a unified model.

Range selection

Engineers use models from psychophysics to predict performances and judgments of people in real life, working, driving, walking. They use these models to predict the absolute values of some quality indexes, such as the visual discomfort. As the judgment of discomfort depends on the participant's exposure to previous glaring stimuli, some investigation is needed on the range of glare exposure in real life. This is done by recording the range of physical stimuli in offices, classrooms, out on the street, as experienced by workers, students, pedestrians and drivers. Then, the practitioners' knowledge about the stimulus range relevant for a given application should be considered in experimental protocols of psychophysical investigations on discomfort glare.

The brute force approach would be to include the stimulus range as an IV in psychophysical experiments, and then in discomfort glare models. It means that each stimulus would be presented after a series of stimuli of controlled range (the responses to these preliminary stimuli would not be recorded in the data), and some delay would be needed between two such series. Unfortunately, such psychophysical experiments would be too time consuming: they are not tractable.

A trade-off between accuracy and tractability is to deliberately choose the stimulus range in an experiment as close as possible to the actual range in the experimental situation we are interested in (the "target situation"). This is what Girard suggested, using simplified scenarios of the situations they were interested in (a driver seeing a series of luminaires, or a couple of vehicles headlamps) to choose the range of luminance, eccentricity, size, etc. of their stimuli [16]. From such real-life scenarios, and from a survey of the photometric properties of the corresponding glare sources, it seems possible to choose a range of stimuli close to what people experience in the target situation. Years ago, Lulla & Bennett suggested that "*in a study on roadway lighting, it would be necessary to provide a maximum luminance similar to that of the roadway lighting*" [27].

This way, the stimulus range in the lab experiment is not an IV, but it is representative of the stimulus range in the target environment, and the experiment is tractable. Indeed, most previous discomfort glare studies tended to tune their stimulus range to the situation under study. For instance, Schmidt-Clausen & Bindels considered glare sources on a horizontal line, which is consistent with a driving scenario with glare due to vehicle headlamps [8]. The merit, if any, of the current paper, is to give a rationale for this scenario-based design of the experimental protocols. An analogy with the panels of participants may help: a panel should also be

representative of the population in the target scenario (students in a classroom, adult drivers, etc.).

The main benefit of this “range selection” approach is to produce absolute values (thresholds) that are relevant for practitioners in the target scenario. The price to pay is that the stimulus range is different indoors and outdoors, with luminaires and with headlamps on the road, with artificial and natural lighting in an office, and so on. It should be tuned differently in the psychophysical experiments dedicated to each of these target situations. One experiment is not enough for all situations, because even if there is a common model of the glare sensation, the glare level depends on the stimulus range. This is not good news, but one needs to accept the reality of the stimulus range effect, and adapt the experimental methodology. Along with this methodological cost, an additional cost of the range selection approach is that for each target situation, a reference scenario needs to be described, and data should be collected in the field to know the range of the glaring stimuli experienced in this scenario.

Conclusion

In the continuum between psychophysics (lab experiments) and ethology (behaviour observation in the field), the stimulus range selection approach stands one degree above psychophysics. The idea is to set the factors known to produce context effects to values representative of the target situation. This approach is of poor value as far as pure psychophysics is concerned, as the resulting models are only valid in the target situations, while psychophysics is in search of more general laws. However, it may be enough for practitioners, and more useful than general models that are not predictive of the absolute values. The next degree is Virtual Reality, where all factors, including the task, approximate the target situation. As we climb the degrees along this continuum, internal validity decreases, while external validity improves [19,46]. The stimulus range selection approach is expected to improve the external validity of the experiments, so that absolute values computed from the models can be relevant for practitioners.

This paper focused on the stimulus range effect but other context effects may be considered with the same approach. On the road, focusing on discomfort glare from the headlamps of oncoming vehicles, the glaring stimuli are seen on the left only (on the right in the UK). An averaging of data collected on the left and right sides of the visual field may be inappropriate. Instead, the stimulus range selection approach may be adapted to the stimulus position effect, considered as a true effect and not as a bias [47].

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