Lux junior 2009
25. bis 27.9.09 Dörnfeld

# Assessment Method for Vehicle Interior Lighting: subjective Responses and objective Measures

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**Abstract**
Interior lighting for vehicles is an issue of dramatically growing relevance in the automotive industry. In the last decade the number of light sources in the car interior has increased drastically. Alongside, the functionalities provided by interior lighting have been enhanced, offering emotional and orientation light as well as a colourful ambience and accompaniment to entry and exit situations.

This paper outlines the requirements for an assessment method for car interior lighting. Many different aspects have to be considered: functionality, perceived interior quality, passengers' physiological needs and subjective impressions. Moreover, different light measurements have to complete this assessment in order to make it repeatable and reliable. These diverse elements have then to be integrated and considered together, in order to have an exhaustive analysis and assessment of the interior lighting system.

## Introduction

Essentially, vehicle interior lighting can be associated in two categories: functional lighting and emotional lighting. The first is normally featured in white light colour and addresses specific needs of the passengers (interior general illumination, reading lights, make-up lights, and so on). The latter (e.g. ambient lighting) not only implies a dramaturgy and an emotional impact, but also addresses the issue of an illuminated environment, from which the passengers shall profit by having a better orientation, an improved interior space perception and a higher perceived quality.

In the last decade Interior lighting for vehicles has experienced an extremely rapid growth. The standard equipment consists of one light source in the centre of the roof, sometimes provided with two reading lights on its sides. Additionally, in each new generation of vehicles new features have been added: foot space illumination, gloves compartment illumination, door sill illumination and make-up lighting. Ambient lighting was fisrt introduced in 1994 as a feature of the BMW 7 series and has been established as standard equipment in cars of the high and middle class segments ever since: this illumination remains on during the night drive and generally in low light conditions and provides a low luminance in more places in the car interior. Due to this increasing number of functions, the number of light sources in the passenger compartment has also multiplied.

This impressive growth has two faces: technology change and customer focus. Nowadays interior lighting, like exterior lighting and more in general architectural illumination, is facing a rapid change of technology. Due to their small space requirements and low energy consumption LEDs are replacing light bulbs as a favourable light source. This is because their qualities enable new design and layout possibilities. On the other hand LED characteristics as a light source still have to be explored and validated: small band spectrum, poor Colour Rendering Index (in case of the white LEDs), expensive selection of the lighting characteristics through binning methods and so forth. That is why LEDs, although having established as standard technology still have unknown points. Additionally, in a few years also OLEDs will be able to be a real alternative in the car interior lighting (1) thus introducing new challenges in this area.
The automotive industry must focus on the customer: he or she must benefit from every technological innovation, which has to be aimed to his or her satisfaction and comfort. Interior illumination, though being considered in many cases a commodity, has a striking impact on how the car interior is perceived a night. It can emphasise design and perceived quality, modelling space in the interior, improve the functionality and the orientation of the passengers and bear them an emotional message as well as a brand-oriented image. It is of upmost importance to implement an illumination which can effectively communicate these features and make them evident to the customer.

## Motivation

In this rapidly evolving environment, an assessment method is needed by the automotive industry in order to correlate the drivers' needs and preferences with the technical possibilities and problems related to the illumination.
Previous studies by Devonshire (2) and Olson (3) (concerning functional lighting), by Grimm (4), as well by Schellinger et al. (5), Klinger and Lemmer (6) (concerning ambient lighting), focused on the minimisation of discomfort and glaring opportunities caused by interior lighting. However, there are no guidelines which indicate how to correctly and consequently arrange lighting in the car interior in order to maximise its positive effects. In fact, this procedure is based nowadays upon experts' personal judgement.
Many studies investigate the effects of lighting on mood (7) (8), emotions (9) and perception (10) (11) (12) (13), within the scope of lighting design in buildings and in office-environments. It is of interest to find out if such effects can even be caused in the relatively small environment of a vehicle and with relatively small luminance levels as in the case of vehicle interior lighting.
Therefore, an assessment method for car interior lighting will be proposed in this paper. On one hand, the understanding of the physiological and psychological needs of the customer has to be researched, as well as the way of translating them in terms of measurable values. On the other hand, the definition of photometric measurement processes has to be undertaken in order to define quality standards for the series development (Figure 1). These measurements should take into account the whole impression of the vehicle interior (from the point of view of the driver and passengers), as well as the single light sources.

## Aspects of the subjective perception

The perception of the visual environment takes place through a pattern-recognition process (14) also called "Look-Up" perception (15). According to this model, the environment is perceived as a whole and then compared with mental concepts. Therefore,

the impact of lighting on the subjective perception of the passengers has to be analysed as a whole, as a complete scenario.

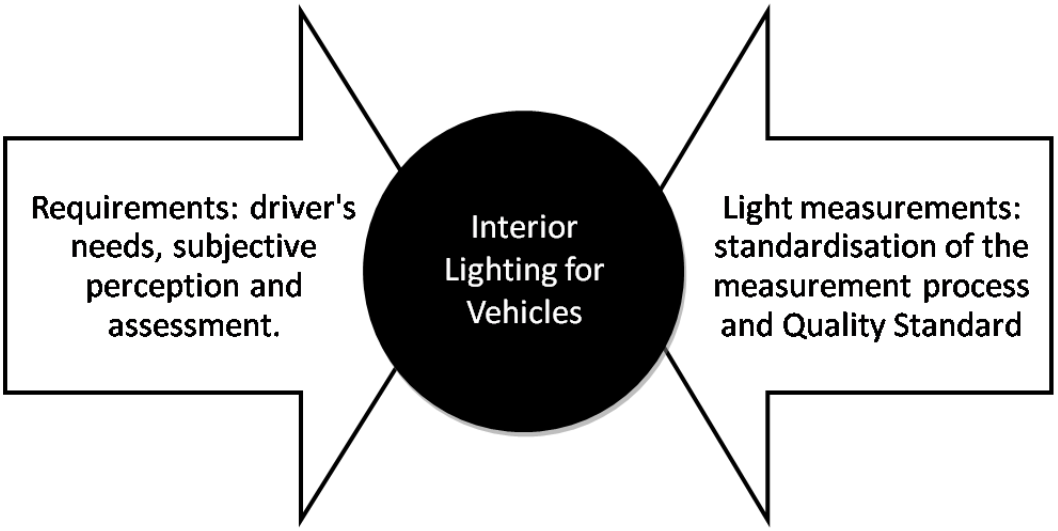
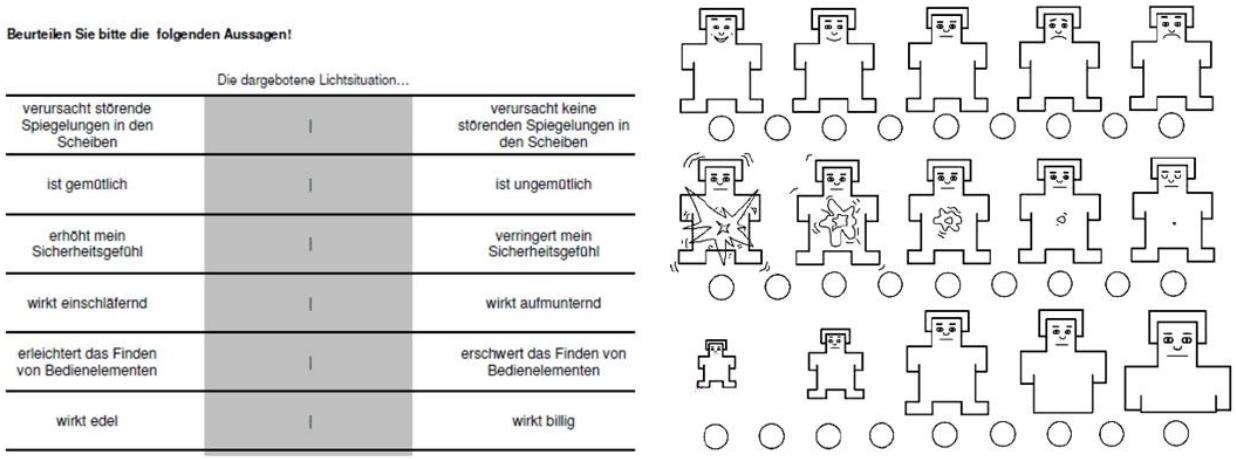



Figure 1: Different aspects in defining vehicle interior lighting

This perception model for example can be applied in the evaluation of ambient lighting, since it dramatically influences the perception of the passenger compartment: design lines and accents, materials, space and distances are perceived differently under different illuminations.
In order to evaluate the effects of ambient lighting on the driver's perception, an experiment has been carried out at the BMW Group research centre: in a controlled simulation environment (16), the test persons had to drive a real vehicle, equipped with diverse ambient lighting fixtures. After driving with a constant ambient lighting scenario, the interior illumination was assessed by means of a questionnaire (as in Figure 2).



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| | | |
|---|---|---|
| verursacht störende Spiegelungen in den Scheiben | \| | verursacht keine störenden Spiegelungen in den Scheiben |
| ist gemütlich | \| | ist ungemütlich |
| erhöht mein Sicherheitsgefühl | \| | verringert mein Sicherheitsgefühl |
| wirkt einschläfernd | \| | wirkt aufmunternd |
| erleichtert das Finden von Bedienelementen | \| | erschwert das Finden von Bedienelementen |
| wirkt edel | \| | wirkt billig |

Figure 2: Extract of the questionnaire for the experiment on the ambient lighting perception. Left: differential pairs for the assessment of the subjective perception. Right: Self Assessment Manikin (SAM) for the assessment of the emotional state after a PAD Model (17).

The results of this experiment showed that ambient lighting has a significant influence on the way the car interior is perceived. The assessment criteria (space perception, interior

attractiveness, perceived quality, functionality, perceived safety) were all affected by changes of the lighting scenario.
In particular, the presence of ambient lighting improved the ratings of each criterion in comparison with a situation without it. These improvements could also be achieved by adopting a small number of light sources. Increasing the number of illuminants or their luminance often caused no enhancement in the assessment while increasing the chance of discomfort glare. This means that a relatively small number of well arranged light sources can achieve the same comfort impression as many brighter illuminants.
Different colours (in the research study blue and orange were tested) also caused diverse assessments, although not always in the same direction: blue light (470 nm) enhanced orientation and functionality, while orange light (605 nm) caused better quality impression and attractiveness.
Notably, these effects were not always coupled with a conscious perception of the light sources. This means that the test persons assessed a change in the visual environment without being able to refer this change to a specific light source.

## Measurements

*Ambient lighting*
In order to completely understand and put into practice the results obtained by the subjective perception analysis different measures have to be carried out. A fish-eye luminance measurement from the driver's point of view gives a helpful overview on the ambient lighting distribution in the car cockpit (Figure 3). Its analysis can focus, in the first place, on possible glaring sources. In the second place, with this measure the lighting environment can be evaluated, comparing it to the luminance distribution needed to obtain a "subjective optimum".

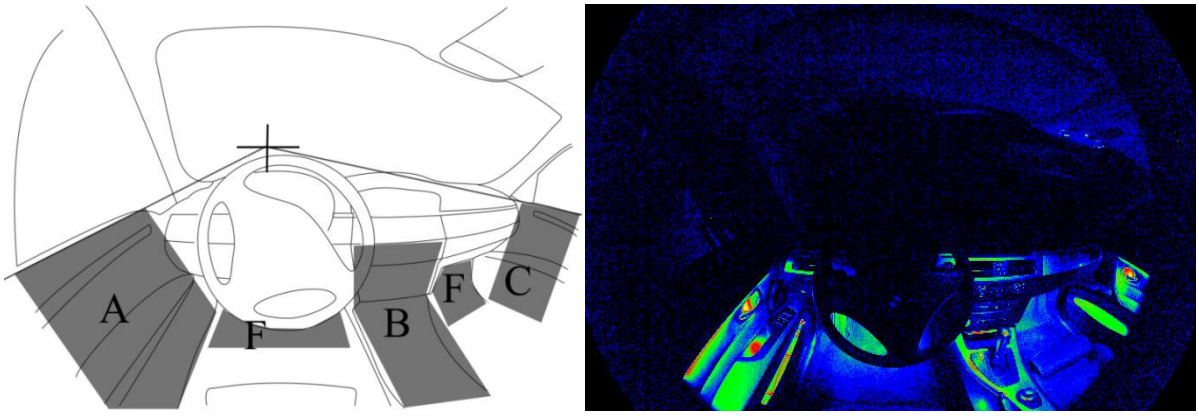

Figure 3: Example of luminance measurement of ambient lighting in car interior. Left – evaluation zones. Right – false colour representation with fish-eye optic.

In relation to the analysis of the "whole picture", the single light source can be measured and characterised (Figure 4). Criteria such as uniformity of the lighting output, luminance peak, uniformity of the colour, can be employed to define the specifications of the single lighting system (e.g. LED and light guide) and its validation process. In this way, also in an early stage of the vehicle development, the specifications for the interior lighting system can be defined, with the aim of obtaining the best subjective response of the driver and passengers.

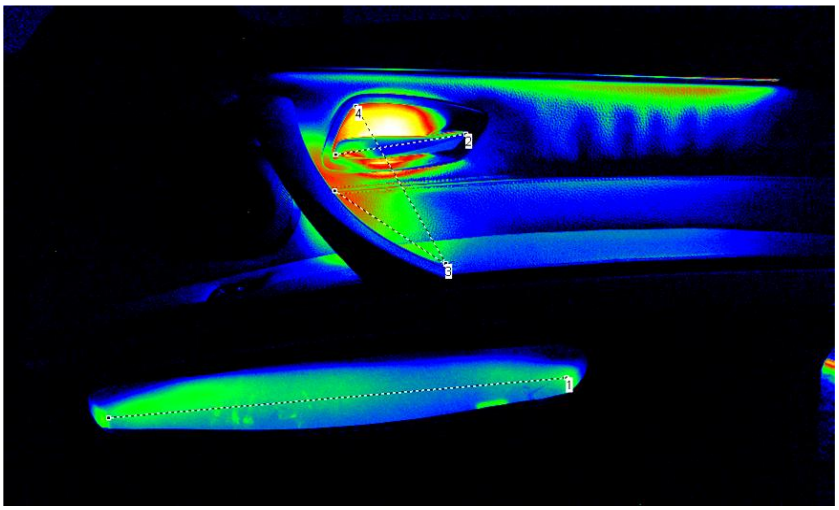

Figure 4: Example of luminance measurement for ambient lighting: right front door, false colour representation.

*Functional lighting*

Measurements of functional lighting can be carried out controlling the following: illuminance and light homogeneity on the target area, complete coverage of the target area, as well as absence of glare for the passengers and the driver and appropriate colour rendering index (e.g. in the case of make-up lighting).

## Conclusions

The outlined method takes into consideration different aspects of the perception and the functionality of interior lighting for vehicles. Its goal is to transform the subjective impressions of the car driver and those of the automotive developer in hard facts, which can easily be communicated to the suppliers and to the development-partners. Moreover, not only the impressions of a small group of experts shall be taken into account, but the effective impact of the interior lighting on the customer.

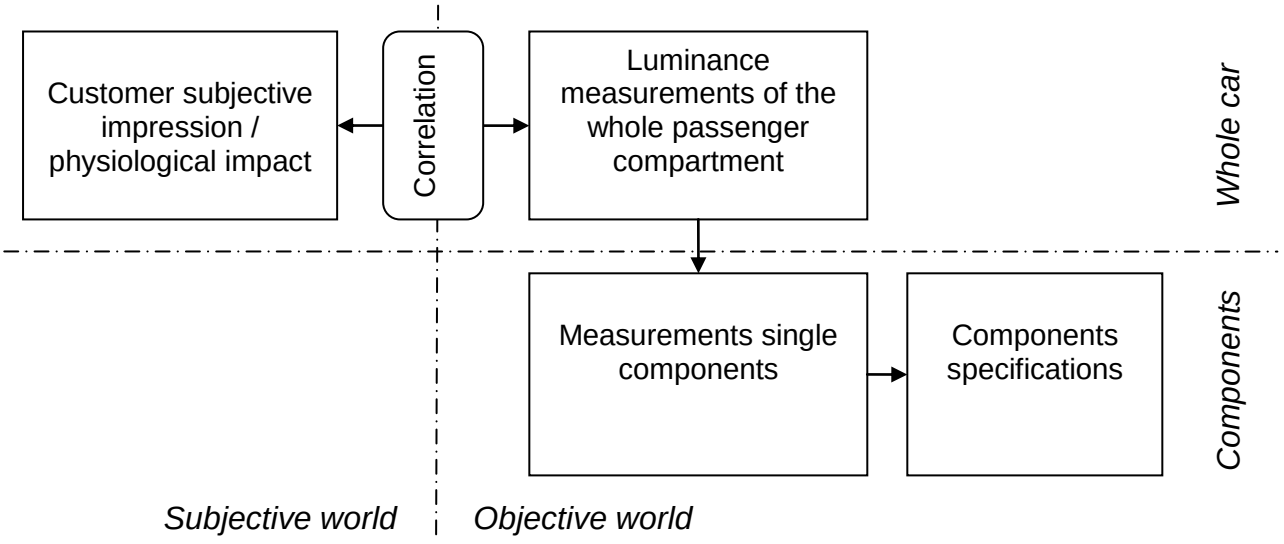


Figure 5: Overview of the assessment method.

The subjective impact can be evaluated in different dimensions: impression of quality, space perception in the car interior, pleasantness and perceived safety. These facets could be resumed in a word: well-being.
The physiological impact can be characterised by measuring required illuminances (for functional lighting) and exceeding luminances (glare rating) during the drive.
Figure 5 illustrates the principle of the method. Customers' subjective impressions and physiological needs have to be compared to photometric measurements in order to attest in which condition an optimal illumination is reached. Since luminance measurement of the lighting distribution gives an indication of what is really perceived by the human eye, it seems a well suitable measurement technique for these exigencies. From the measurement of the whole car interior it can be determined where appropriate light sources have to be placed and which level of homogeneity and luminance they should provide. These dimensions have to be defined and with convenient tolerances and quality specifications, to be delivered to the suppliers. In respect of these needs, measurement standards then have to be defined.

These two perspectives, the objective and the subjective worlds, have to be brought together, connected and harmonised in order to succeed in the task of having a customer-oriented car interior lighting.

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