

Study on the Perception of High Visibility Level Values

Simon Vogel M.Sc.^{1,*}, Saba Nouzari¹, Dr.-Ing. Mathias Niedling¹, Prof. Dr.-Ing. habil. Stephan Völker²

¹Research Institute of Automotive Lighting and Mechatronics (L-LAB), HELLA GmbH & Co. KGaA, Rixbecker Straße 75, 59552 Lippstadt

²Technical University of Berlin, Chair of Lighting Technology, Faculty of Electrical Engineering and Computer Science, Einsteinufer 19, 10587 Berlin

*Corresponding author: simon.vogel@l-lab.de

Abstract

For the development of new lighting functions of modern automotive headlamp systems suitable quality factors are needed to evaluate the driver's visual performance. The Visibility Level (VL), which compares the contrast of an object with its threshold contrast, has proven to be one of these quality factors. While the perception of small VL values have been extensively investigated, high VL values have not been assessed. Results can help to determine how much light is actually needed to illuminate a situation sufficiently so that vehicles can drive without a loss of safety but at a reduced energy consumption.

Here the results of a study in the light tunnel facility of the HELLA GmbH & Co. KGaA in Lippstadt are presented. After the generation of different light distributions, the object luminance is measured and the different VL values of the viewing target are estimated.

In the first part of the study a praxis factor for this scenario is determined, which is used for the calculation of the actual VL. The praxis factor equals 10.27.

In the second part of the study different light distributions, which create different VL values from 4 to 120, are then shown to and assessed by the study participants. The evaluation shows a saturating assessment of VLs higher than 90. Viewing targets with a VL above this value are all equally described as perfectly visible. A VL above 65 leads to a well visible target.

These results are a starting point for upcoming work regarding the generation of new light distribution, such that light will be brought to the streets more adequately.

Index Terms: Visibility Level, visual performance, empirical study, light distributions, headlamp, automotive lighting



1 Introduction

1.1 Motivation

Future automotive headlamp systems will be more intelligent and more connected than their present predecessors. Precise adaptation to different scenarios and conditions based on the drivers needs will be provided by changing their light distribution accordingly [1].

To generate and evaluate these new light distributions a suitable visual performance model is required [2]. In this context visual performance describes the performance of a human regarding a visual task like detection or identification of a target. Ideally, the visual performance, which leads to an action in the driving task, can be predicted by controllable parameters. The illuminance caused by the headlamp creates contrasts of objects within the light distribution in a specific environment, which then can be assessed with a visual performance model.

The visual performance model examined is the Visibility Level (VL) as proposed in the CIE report 19/2 [3]. The VL model compares the contrast C of a target with the threshold contrast C_{th} based on Blackwell's psychophysical data [4]:

$$VL = \frac{C}{C_{th}} \quad (1)$$

Thus, a VL of 1 means that the target is just visible under laboratory conditions.

While the determination of the VL is more complex than of usual performance indices of headlamps like their illuminance distributions on the street [5], the VL instead is directly connected with the detection task. Since according to the CIE [6] the detection of an object is the key step in the attention-detection-recognition pipeline, the VL is much more suitable to evaluate the illumination of a scene regarding the resulting traffic safety.

1.2 Research question

In this study VL values up to 120 are examined with focus on their perception and evaluation by test persons. The main research questions are:

1. Does the perception of differences between VL values decrease for increasing VL values?
2. Is there a threshold VL value that indicates an indistinguishability for exceeding VL values?

Both questions are expected to be answered positively.

Comparable observations were presented in [7]. However, those results were not presented under real situations but instead on a computer screen. It has also been shown in the past, that a reduction of light is still assessed as sufficiently enough [8][9].

While these examinations did not focus on the visibility of a specific viewing target similar result are expected for the VL.

2 Design of the study

The study was realized in the light tunnel of the HELLA company in Lippstadt, Germany. The light tunnel is a 140 m long dark hall with two asphalted lanes and exemplary lane markings, such that realistic night driving conditions can be realized even during the day. The light tunnel is equipped with modern video projectors capable of a luminous flux output of 60 000 lm as well as different headlamp systems to realize different light conditions.

20 test persons (15 male, 5 female) with an average age of 31.3 ± 8.9 years took part in the study. All of them were employees or students of HELLA, therefore their knowledge about automotive lighting is above the average driver. 15 of them used either glasses or contact lenses during the study. The 20 test persons were split into 5 groups of 4 people.

2.1 Study setup



Figure 1: Study setup in the light tunnel, 4 test persons were positioned next to each other behind the video projectors looking along the road at the viewing target.

The setup for the study is shown in **Figure 1**. The test persons are seated with a distance of 1.5 m between each other behind the light sources. To guarantee perfect viewing positions the back-row seating level is slightly elevated.

Two Barco HDF-W30 Flex projectors are used as the light sources as shown in **Figure 2**. The projectors have a resolution of 1920 x 1200 pixels and 8 Bit output levels. They are positioned in height (0.65 m) and width (1.30 m) as well as orientation to the lane

markings according to ECE R48. The console on the left in **Figure 1** controls the light output.

The viewing target is shown in **Figure 3**. It is a 30 cm x 30 cm sized cardboard square painted in dark grey with a reflectivity ρ of 5,2 %. It is positioned 50 m ahead of the test persons in the middle of the driving lane, perpendicular to the road surface.

A precise draft with all the different distances is shown in **Figure 4**.

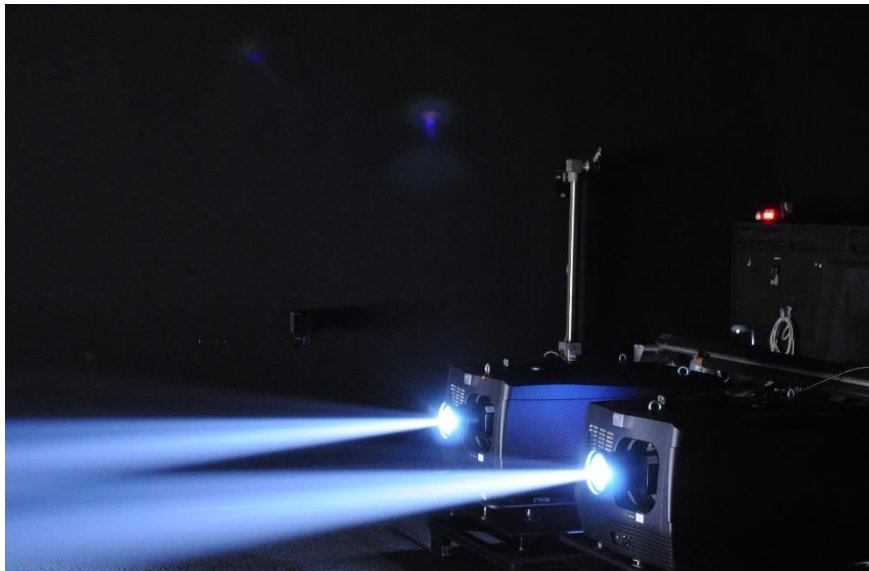


Figure 2: Two Barco HDF-W30 Flex projectors serve as the light sources; they have sufficient luminous flux output of 30 000 lm each and can precisely imitate light distributions of headlamp systems.

2.2 Study execution

The study consisted of two different tasks.

1. The test persons were asked for their ability to detect the viewing target for decreasing and increasing VLs.
2. The test persons were asked to rate the visibility of the viewing target with 6 different grades for a variety of different VLs.

The test persons were explained each task individually so that they had time to ask questions. The adaptation time was limited to 1 minute as a trade-off between economical study execution and decreasing dark adaptation slopes [10].

First, the visibility threshold was determined to calculate the relevant praxis factor of the viewing scenery, which is required for the computation of the VLs. For this the first task was split into two parts with incrementally decreasing and increasing light output. The test persons were asked to check a box when the viewing target, which was presented to them beforehand, was detectable. For the decreasing light output the test

persons could all recognize the viewing target in the beginning. They stopped checking the box once crossing a threshold. For the increasing light output the viewing target started undetectable and then became visible after crossing the threshold. Using the method of limits [11] the actual threshold of perception is calculated by the average of both approaches.



Figure 3: Grey square board with a size of 30 cm and a reflectivity ρ of 5.2 %, positioned 50 m ahead of the test persons in the middle of the driving lane served as the viewing target.

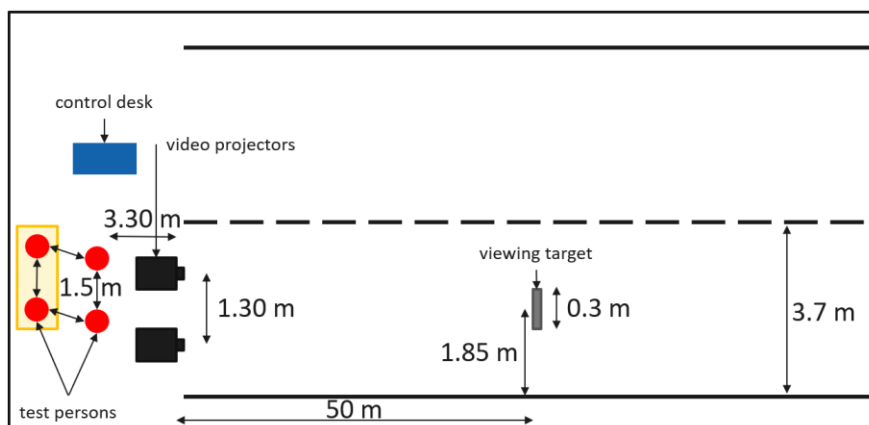


Figure 4: Draft of the study setup in the light tunnel, test persons located on the left, behind the video projectors, viewing target 50 m ahead of the projectors in the middle of the lane.

In the second task the test persons reviewed 80 different light distributions with varying VLs. These light distributions were created by scaling the standard asymmetrical low beam distribution. The test persons used grades from 1 (very poorly visible) to 6 (perfectly visible). The contrast of the viewing target was always above the threshold contrast; thus, the target was never undetectable for the test persons in this part of the study. The 80 light distributions were shown in a random order to prevent any order effects. To give the test persons the opportunity to create their own evaluation framework, the first 10 distributions were not evaluated. They also contained the maximum as well as the minimum VL of the study. Each light distribution was shown for 5 seconds followed by 5 seconds of no light.

3 Results

The analysis of the results combine the VL, which is extracted from luminance measurements and enhanced by the precise praxis factor results of the first part of the study, with the actual evaluation of the visibility of the viewing target, which was the second part of the study.

3.1 Luminance measurement and theoretical Visibility Level

Each light distribution was measured prior to its presentation to the test persons with a TechnoTeam LMK 5 Color luminance measuring video photometer. An exemplary picture is shown in **Figure 5**.

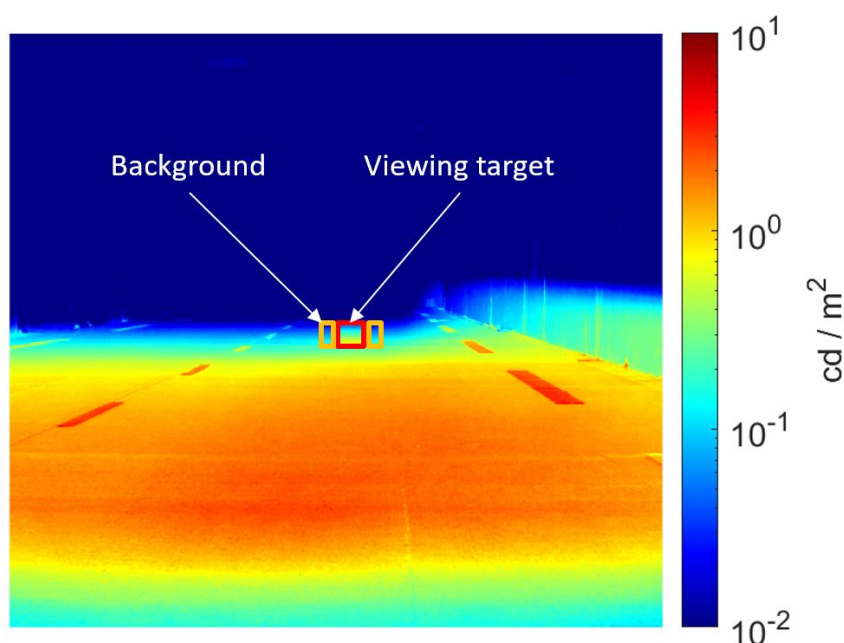


Figure 5: Luminance measurement of the scene with TechnoTeam LMK 5 Color, viewing target located 50 m ahead of the camera in the middle of the lane, areas for the calculation of the contrast are shown in red (object luminance) and orange (background luminance), the size of the viewing target is 29.4'.

The viewing target's VL is then calculated from the luminance measurement using the model of Kokoschka und Gall [12] as explained in the following section.

The VL is the ratio of contrast and threshold contrast (see **Equation (1)**). According to Weber the contrast equals

$$C = \left| \frac{L_O - L_B}{L_B} \right|, \quad (2)$$

with the luminance of the object L_O and the background luminance L_B . The object luminance is the mean of the luminance of the object area (red area), while the background luminance is averaged over two rectangulars with half the square's width left and right of the object (orange areas) as shown in **Figure 5**. The actual threshold contrast consists of three components

$$C_{thr,actual} = C_{thr,theoretical} \cdot PF \cdot TSF. \quad (3)$$

$C_{thr,theoretical}$ is the theoretical threshold contrast based on the Blackwell data, PF is the praxis factor, which describes the complexity of the viewing situation (in this case estimated to be around 10 according to Kokoschka [13]). The TSF is the transient threshold increment factor (German: **Transienter Schwellenerhöhungsfaktor**), which considers the influences of a very inhomogeneous luminance distribution in the scenery.

The theoretical threshold contrast is calculated according to

$$C_{thr,theoretical} = C_{min} \cdot \left(1 + \left(\frac{L_a}{c_1} \right)^{c_2} \right) \cdot \left(1 + \left(\frac{\alpha_0}{\alpha} \right)^2 \right) \quad (4)$$

$$\alpha_0 = c_3 + c_4 \left(1 - \frac{1}{1 + \left(\frac{L_a}{c_5} \right)^{c_6}} \right) \quad (5)$$

$$C_{min} = 0.00275, c_1 = 0.185, c_2 = -0.484, c_3 = 7.5, c_4 = 133, c_5 = 0.00075, c_6 = -0.383$$

with L_a being the adaptation luminance and α the size of the viewing target in angular minutes. The adaptation luminance L_a is calculated as the mean luminance of an ellipsis with a width of 10° and 2° height focused on the middle of the street as proposed in [14].

The transient threshold increment factor is calculated with

$$TSF = \frac{1}{4} \frac{(1 + L_B/L_a)^2}{L_B/L_a} \quad (6)$$

using L_B – the background luminance – and L_a – the adaptation luminance. All these input parameters but the praxis factor can be deduced from the luminance measurement. The praxis factor itself must be determined during the first part of the study. The veil luminance is ignored in this examination.

3.2 Determination of the praxis factor

In the first part of the study 20 different light distributions with incrementally decreasing and increasing light output were shown to the test persons. These light distributions were measured beforehand and a theoretical VL was calculated using an estimated praxis factor of 10. The actual praxis factor is to be calculated from the results.

The test persons checked the visibility of the viewing target for each light distribution. The results are shown in **Figure 6** and **Figure 7**.

The detection ratio is the ratio of people detecting the viewing target and the total amount of test persons (17 persons in this case, 3 test persons did not follow the instructions properly).

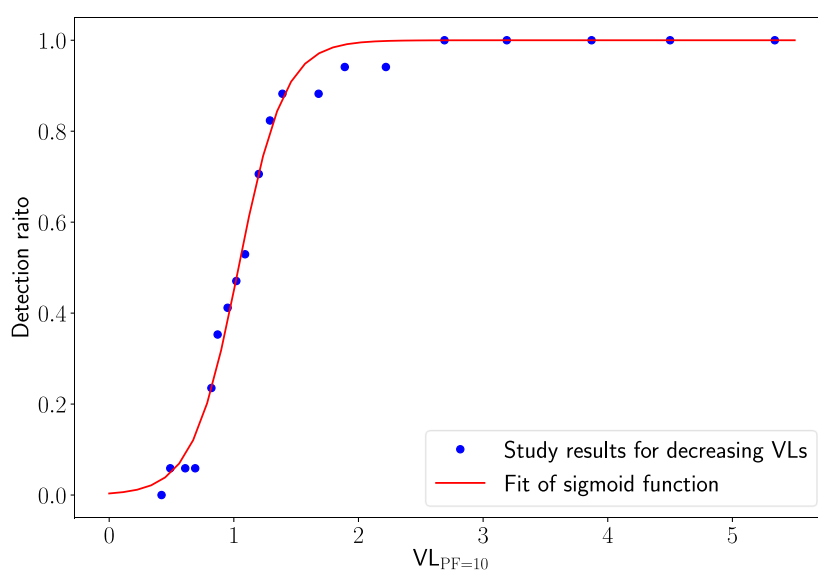


Figure 6: Detection ratio of the viewing target of 17 test persons for 20 different light distributions, the light distributions were assigned different VL values according to the luminance measurements using a fixed praxis factor, the distributions were shown in order of **decreasing** VLs, a theoretical sigmoid function was fitted to the data to determine the praxis factor.

A psychometric function $f(VL)$ presented as a sigmoidal distribution in the form

$$f(VL) = \frac{1}{1 + e^{a \cdot (VL - b)}} \quad (6)$$

was fitted to the data using the method of least squares. According to theory fit parameter b should be 1, which means that at a VL of 1 the detection ratio is equal to 0.5. A deviation means that the VL has to be calculated using a different praxis factor.

The calculated values are for decreasing VLs

$$a_{decr} = -5.46 \pm 0.37,$$

$$b_{decr} = 1.038 \pm 0.012,$$

and for increasing VLs

$$a_{incr} = -8.14 \pm 0.38,$$

$$b_{incr} = 1.017 \pm 0.006.$$

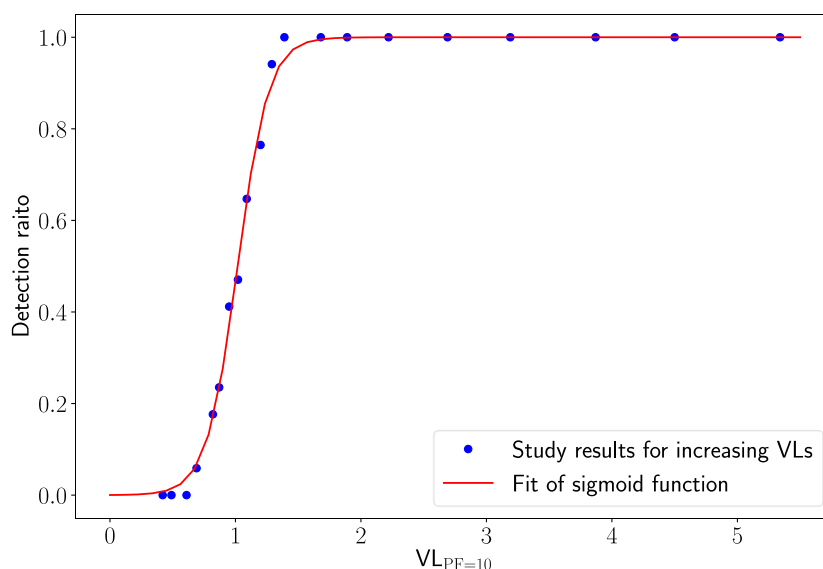


Figure 7: Detection ratio of the viewing target of 17 test persons for 20 different light distributions, the light distributions were assigned different VL values according to the luminance measurements using a fixed praxis factor, the distributions were shown in order of **increasing** VLs, a theoretical sigmoid function was fitted to the data to determine the praxis factor.

This means that the calculated VL values calculated using a praxis factor of 10 are not perfectly scaled. The detection ratio equals 0.5 for a VL of 1.027 ± 0.007 (mean of b_{decr} and b_{incr}) instead of 1. Therefore, the actual VL values have to be scaled with a praxis factor, which takes these results into account.

Thus, the new praxis factor equals

$$PF = 10.27 \pm 0.07.$$

These results underline the theoretical expectations. The calculated praxis factor is only slightly higher than 10. This is in line with previous observations. The data fits to the sigmoid function with errors below 7%. All this could be achieved with less than 20 test persons. Additional study participants most likely would have resulted in even better agreement with the theory.

3.3 Evaluation of different Visibility Levels

Using the actual praxis factor the VL values of the 70 different light distributions were calculated. Their assessment by the test persons is shown in **Figure 8**.

The VL values varied from approximately 4 to 120. The evaluation by the test persons is averaged over all 20 persons and the standard deviation is shown in the error bars. For easier allocation the different grades are separated by thin grey lines.

The data shows clearly that there are two different behaviors within the assessment of the VL. For values up to roughly 90 there is a clearly linear performance (slope $a = 0.047$, $R^2 = 0.953$). After that the improvement of the target's visibility is heavily decreasing, which results in a nearly saturated behavior (slope $a = 0.0096$, $R^2 = 0.746$). The mean assessment for this segment is above 5.5.

The grade 5 (well visible) is on average reached for a VL of 65. For VLs above 40 the visibility is evaluated rather good than bad.

All these results underline the expected answers to the research question. The perception of the differences between different VLs decreases for very high VLs. And there seems to be a threshold VL (in this case 90) that indicates an indistinguishability of exceeding VL values.

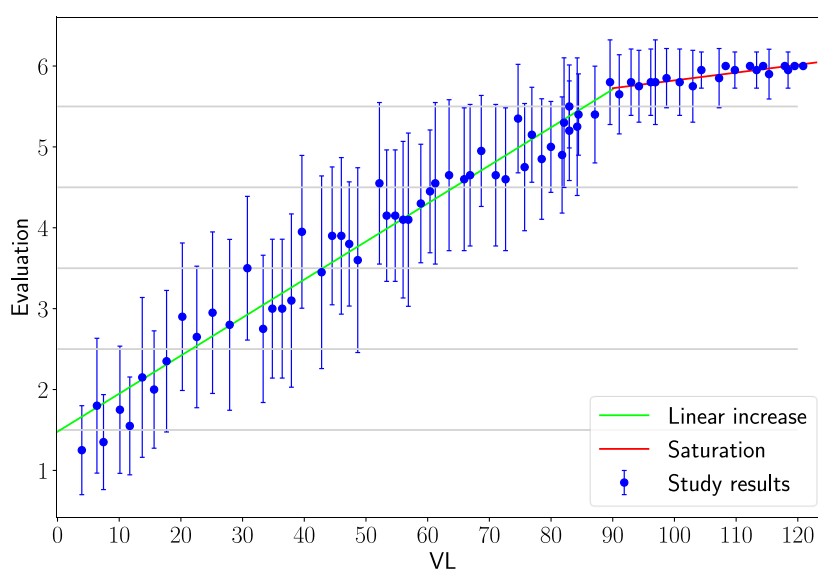


Figure 8: Evaluation of the visibility of a viewing target by 20 test persons with grades from 1 (very poorly visible) to 6 (perfectly visible) in relation to the measured and calculated VL values varying from approx. 4 to 120; two different trendlines are fitted to the data showing first a linear increase, which then evolves into a saturating behavior above a VL of 90.

4 Summary & Outlook

4.1 Summary

In this study 20 test persons evaluated 70 different VL values ranging from approximately 4 to 120. The research hypothesis that the improvement in visibility saturates for high VL values is confirmed by the results. VL values above 90 are reviewed as equal. VL values above 65 are assessed as resulting in a good visibility for the driver, however this good visibility can still be improved by further increasing the VL.

4.2 Outlook

These results give a first impression of the perception of high VL values. While their suitability for real-life situations still has to be proven and further studies – for example with test persons with more average automotive lighting experience as well as with a higher average age – are needed, the VL will potentially establish as a quality factor for the development of light functions for automotive headlamp systems as well as modern street lighting installations. Such that in the future instead of illuminance values VL reference values will be used to determine the traffic safety of new systems.

5 References

- [1] J. Damasky, W. Huhn, “Variable Headlamp Beam Pattern – Lighting Requirements for Different Driving Situation”, SAE Technical Paper 970647, 1997.
- [2] R. Brémond, “Visual Performance Models in Road Lighting: A Historical Perspective”, LEUKOS, 2020.
- [3] Commission Internationale de l’Eclairage, “An Analytic Model for Describing the Influence of Lighting Parameters upon Visual Performance”, CIE publication 19/2, Vienna, 1981.
- [4] H.R. Blackwell, “Contrast thresholds of the humane eye”, Journal of the Optical Society of America, 1946.
- [5] S. Völker, “Vergleich unterschiedlicher Kriterien für die Bestimmung der Sichtweite von Kfz-Scheinwerfern”, Lux junior 2001: 5. Forum für den lichttechnischen Nachwuchs, Dörnfeld/Ilm, 2001.
- [6] Commission Internationale de l’Eclairage, “Fundamentals of the visual task of night driving”, CIE Technical Report 100, Vienna, 1992.
- [7] G. Paulmier, C. Brusque et al., “The influence of visual complexity on the detection of targets investigated by computer generated images”, *Lighting Research & Technology* 33(3), 2001.

- [8] P. Janke, A. Thoma et al., „Dimmung des Scheinwerferlichts für zukünftige Elektrofahrzeuge“, Lux junior 2019: 14. Internationales Forum für den lichttechnischen Nachwuchs, Dörfeld/Ilm, 2019.
- [9] M. Wagner, A. Erkan et al., “Reducing Head Lighting Level on Urban Roads for Different Street Lighting Situations”, 13th International Symposium on Automotive Lighting, Darmstadt, 2019.
- [10] R. Greule, “Kontrastschwellen bei transienter Adaptation”, Dissertation, Lichttechnisches Institut, Universität Karlsruhe, 1993.
- [11] E.B. Goldstein, “Wahrnehmungspsychologie: eine Einführung”, Spektrum Akad. Verlag, Heidelberg, 1997.
- [12] S. Kokoschka, D. Gall, “FASIVAL – Entwicklung und Validierung eines Sichtweitenmodells zur Bestimmung der Fahrersichtweite: Abschlussbericht“, 2000.
- [13] S. Kokoschka, “Zur Berechnung von Schwellenkontrasten für die Detektion einfacher Sehobjekte“, Licht 4, 1988.
- [14] J. Winter, “Typical eye fixation areas of car drivers in inner-city environments at night”, Lux Europa 2013, Krakau, 2013.