Influence of Inhomogeneous Fields and Glare Sources on Visual Performance

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Abstract

For the calculation of mesopic luminances according to CIE:191 it is of interest what the current adaptation state of the human visual system is. The experimental basis for those mesopic luminances is a series of laboratory experiments, where the visual performance of human observers were measured under homogeneous conditions.

Real world environments, such as inner city streets at night, can be very inhomogeneous when lights of other vehicles, traffic signals or illuminated shops are taken into account.

In order to find out what the influence of inhomogeneous fields and glare sources on visual performance is, and therefore on the correspoding adaptation state, the following research design has been created: a homogeneous sphere, illuminated with a spectrally programmable light source, was used to provide an adaptation luminance of $1\ \frac{cd}{m^2}$ with a white LED spectrum with a S/P ratio of 1.71. A $1°$ square is projected as a sweep with the same spectrum programmed to provide increasing luminances until detected by a human observer, with and without a glare source. The glare source is located at $2.88°$ and $4.87°$ left of the line of sight, causing a vertical illuminance of $1\ lx$ at the eye of the observer. The contrast threshold is measured at $0°$ and at $10°$ eccentricity at the right hand side for foveal and peripheral performance. A $5°$ circle with the same spectrum was projected at $10°$ eccentricity on the left / right, and at $0°$ eccentricity in order to influence the visual performance.

Glare has a significant impact on foveal visual performance when applied to a homogeneous background. Increasing the luminance locally in the $5°$ circle improves the foveal visual performance significantly. Glare has no influence on foveal visual performance when the luminance has been increased locally and its impact is reduced if a brighter area is present in the visual field.

The data of this investigation seems to indicate that the visual performance is even better than with the here presented modifications to the homogeneous laboratory environment. Therefore the mean luminance of the road surface seems to be a good predictor for the adaptation state of the visual system to use for calculation of CIE:191.

Keywords. Visual Performance, Inhomogeneous Field, Contrast Threshold, Glare

1 Introduction

For the application of the mesopic luminances according to CIE:191 [4] the current adaptation state of a typical observer has to be used for calculation. However it is currently not defined how the adaptation state shall be calculated or estimated for the application in street lighting. In street lighting the scene for an observer is rather heterogeneous. It consists of a more or less homogeneous street surface, buildings or gardens, illuminated or dark areas. The own vehicle producing a low or high-beam head light, oncoming vehicles generating psychological and / or physiological glare in the observers eye and not to forget the street luminaires itself.

The influence of background luminance on visual performance i.e. e.g. contrast threshold is well known (Blackwell 1946, 1971) and can be calculated as described by Adrian 1989 [2, 3, 1]. But the proposed methods are for homogeneous backgrounds only.

Uchida and Ohno 2012, 2013 undertook subject experiments with the conclusion that adaptation is locally dominated [6, 7].

The influence of glare in street lighting is described in CIE:31. Glare produces a veiling luminance at the observers eye, decreasing the visual performance [5]. A predictor for that impact is the threshold increment (TI) value.

This investigation addresses the issue of analyzing the influence of inhomogenities and glare on visual performance. Firstly it is assumed that glare increases the contrast threshold as calculated according to the TI values of CIE:31. Secondly the hypothesis is tested whether the adaptation state of the visual system is influenced locally. If that would prove true a certain offset luminance projected on the target area would decrease the contrast threshold as calculated according to Adrian. If a local luminance offset would influence the adaptation state, that would also decrease the TI value, resulting in a less distinct increment.

2 Methods

A subject experiment has been designed in order to assess the influence of inhomogeneous adaptation fields and glare on visual performance. The dependent variable is the visual performance operationalized via contrast threshold. The independent variables are glare (*withGlare*, *withoutGlare*), offset luminance (*NoOffset*, *FovealOffset*, *PeripheralOffset*, *PeripheralOffsetOppositeSide*) and target position (*foveal* $0°$, *peripheral* $10°$). The experiment was conducted with the ascending method of limits.

A homogeneous sphere (radius $= 0.31\ cm$) was illuminated from above with a spectrally programmable light source. Almost any desired broadband spectrum in the range from $380\ nm - 780\ nm$ and background luminance of up to $5\ \frac{cd}{m^2}$ can be synthesized by the investigator (see figure 1). The target-actual comparison of a synthesized spectrum is depicted in figure 3a. The light source of a pico-projector has been replaced by another spectrally programmable light source and again the investigator can recall any desired spectrum and target luminance. For each of the light sources a calibration file was created in order to create accurate spectra, once every while. At the beginning of every day a correction factor measurement has been undertaken in order to compensate for the deprecation of the light source, which deteriorates by approximately 0.5% per hour in use. The parameters for the values have been chosen to represent typical lighting situations in inner city traffic.

Visual performance was operationalized by contrast threshold, which again is measured by projecting a square with an increasing luminance sweep at the foveal / peripheral position (ascending method of limits). The sweep consisted of 150 single spectra, presented over a time of $22.5\ s$ with a fixed contrast range starting at a contrast of $C_1 = 0.005$ and ending at $C_{150} = 0.6$, depending on

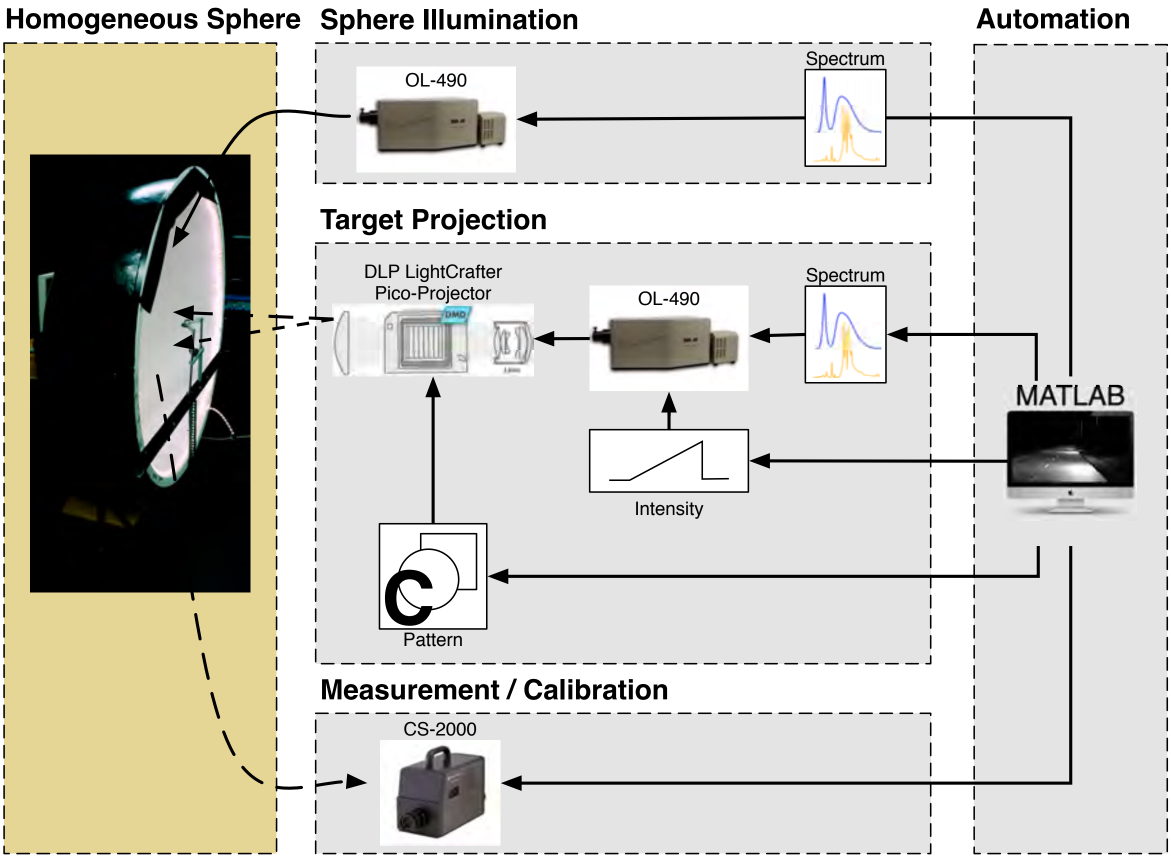


Figure 1: The schematic of the used devices for the subject experiment.

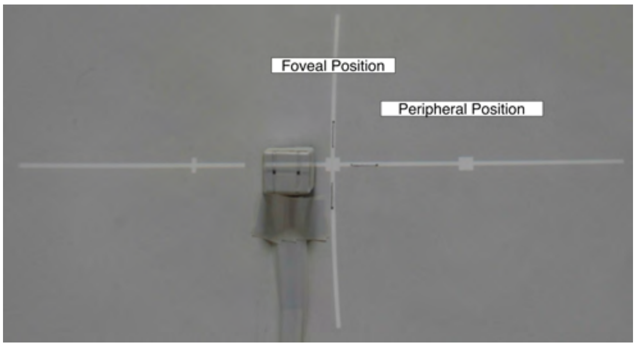
the current chosen background luminance. The target was a $1°$ square which can be projected at a foveal and a peripheral position at $0°$ and $10°$ eccentricity on the right hand side (see figure 2a). The background luminance of this experiment was $1\ \frac{cd}{m^2}$ with a white LED spectrum as depicted in figure 3a.

The inhomogeneous adaptation field was generated by another white LED light source and represents a laboratory mock up of the low beam of a vehicles headlamp. The disturbance was a $5°$ circle which center was projected at either the foveal (later on called *FovealOffset*), right peripheral (*PeripheralOffset*) or left peripheral (*PeripheralOffsetOppositeSide)* position adding another $5\ \frac{cd}{m^2}$ to the background luminance (see figure 2b).

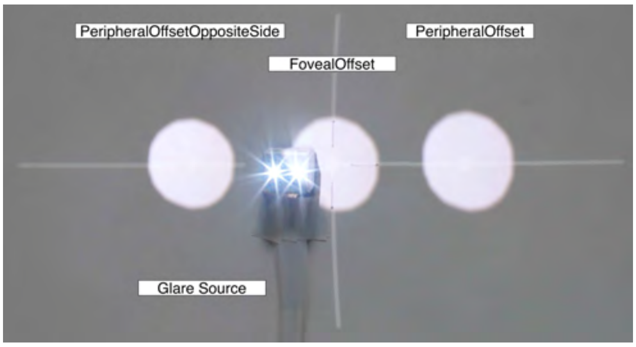
The glare source represents an oncoming vehicle at $50\ m$ distance producing $1\ lx$ vertical illuminance at the observers eye (the spectrum can be seen in figure 3b). It consists of two white LEDs at $2.88°$ and $4.87°$ eccentricity left of the foveal axis. The left LED has a luminance of $70\ \frac{kcd}{m^2}$, the right one a luminance of $40\ \frac{kcd}{m^2}$, but both contributing equally $0.5\ lx$ to the vertical illuminance at the observers position. When in use has been switched on $2\ s$ before the sweep starts and remained on until the subject presses the button. The background luminance created a vertical illuminance at the observers eye of $3.3\ lx$, the offset light source a vertical illuminance of $0.2\ lx$.

An experiment can be easily created by the investigator with a xml file, where all parameters (i.e. spectra, luminances, sweep parameters, etc.) can be adjusted. The whole experiment is completely automatized and its order randomized. Each parameter combination is repeated two or three times (randomly chosen) in order to make it hard for the subject to guess the next target position. Each offset mode is tested separately in random order.

N = 29 subjects participated in the experiment. They received a remuneration of 10 € as

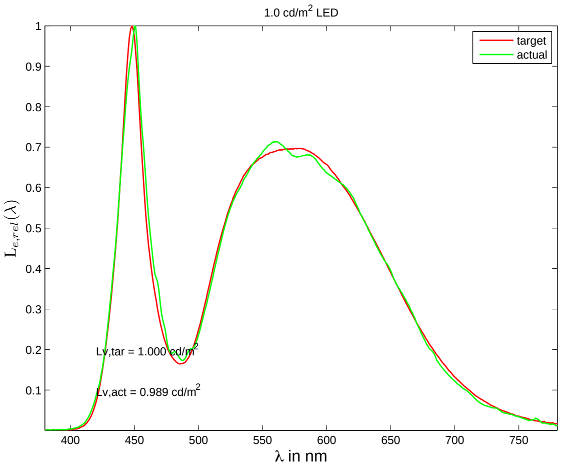


(a)

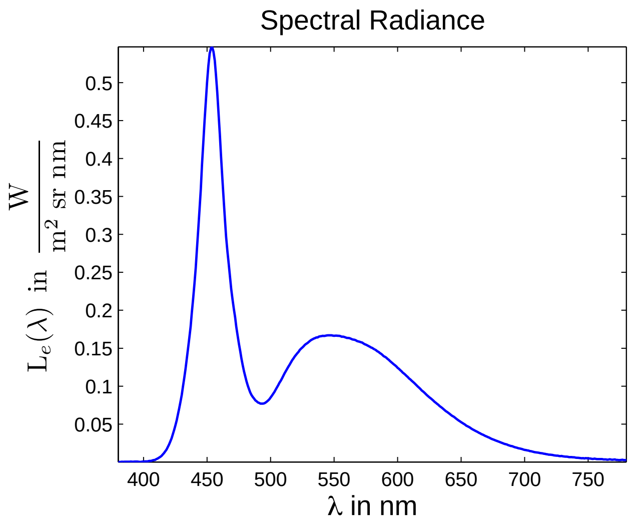


(b)

Figure 2: The $0°$ foveal / $10°$ peripheral target position, the glare source and the offset disturbance. The projected cross is for alignment purposes of the pico-projector and the offset light source before the experiment, only.



(a) The synthesized spectrum of the white LED with a S/P ratio of 1.71 and a CCT of $4322\ K$.



(b) The spectrum of the white LED glare source with a S/P ratio of 2.7 and a CCT of $13665\ K$.

Figure 3: The spectra used within this experiment.

compensation. Their age was 26.6 ± 3.6, 6 of them were female. None of the subjects required visual aids. At the beginning of each experiment each subject's visus was tested to fulfill a visus of 1.0 and for color-blindness. The data presented in the following is part of an experiment where additionally to the here described parameters the spectrum and background luminance has been altered. Before each experiment the subject had $10\ min.$ to adapt to the homogeneous background luminance before the experiment started (without the offset light source). The task of the subject was to focus on a cross (with a white center) at the foveal position. The subjects were asked to press a button once they've detected the target and announce whether it was on the foveal or peripheral position.

At the end of the day each projected spectrum (background and the ones for the target where subjects pressed the trigger) was measured with a spectroradiometer in order to document the accuracy of the programmable light sources and to measure a more precise contrast. The measured values for the background luminance L_B and the target luminance L_t were used for calculation of the contrast as follows: $C = \frac{L_t - L_B}{L_B}$. The L_t and L_B are measured with a switched off glare source.

The theoretical influence of glare was evaluated via the TI value, which is calculated as seen in equation 1, where glare source k at the angle Θ_k to the line of sight is causing a vertical illuminance E_k in the observers eye, which egain results in the veiling luminance L_v.

$$TI = \frac{65\ L_v}{\overline{L}^{0.8}}\%, \quad L_v = 10 \sum_{k=1}^{n} \frac{E_k}{\Theta_k^2} \tag{1}$$

3 Results

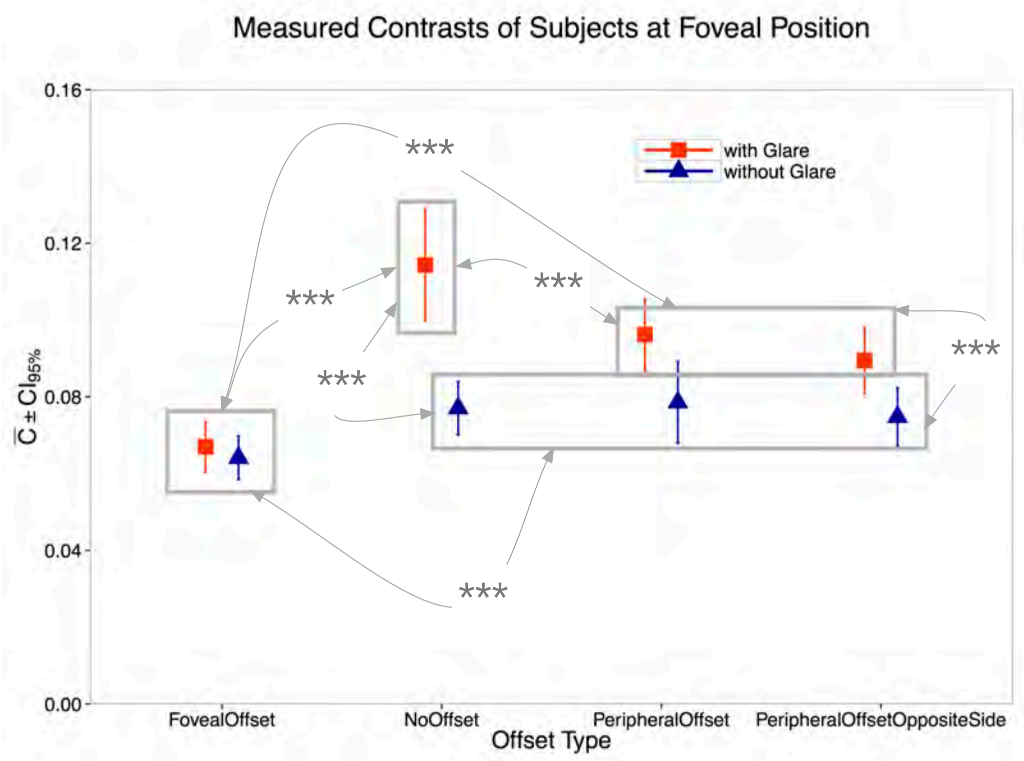


Figure 4: The measured contrasts at the foveal target position at 0° eccentricity for N=29 subjects. Not significantly differing contrasts are grouped with gray rectangles, significant differences are marked with stars.

Table 1: The percentual differences for foveal contrasts referring to the reference value *NoOffset* without glare.

Reference	without glare			with glare			
	Foveal Offset	Peripheral Offset	PeripheralOffset OppositeSide	NoOffset	Foveal Offset	Peripheral Offset	PeripheralOffset OppositeSide
NoOffset without glare	-16.5 %	3.1 %	-2.6 %	45.7 %	-12.6 %	29 %	17.3 %

The results of the measured contrasts for the foveal visual performance can be seen in figure 4 and table 1. The reference contrast is offset type *NoOffset* without glare. Compared to the reference the contrast for *FovealOffset* is reduced very highly significantly, whereas *PeripheralOffset* and *PeripheralOffsetOppositeSide* don't have an impact on foveal visual performance without glare.

Glare has a very high significant impact on foveal visual performance for offset type *NoOffset*. There is no significant impact with *FovealOffset*, but again highly significant for the peripheral offsets.

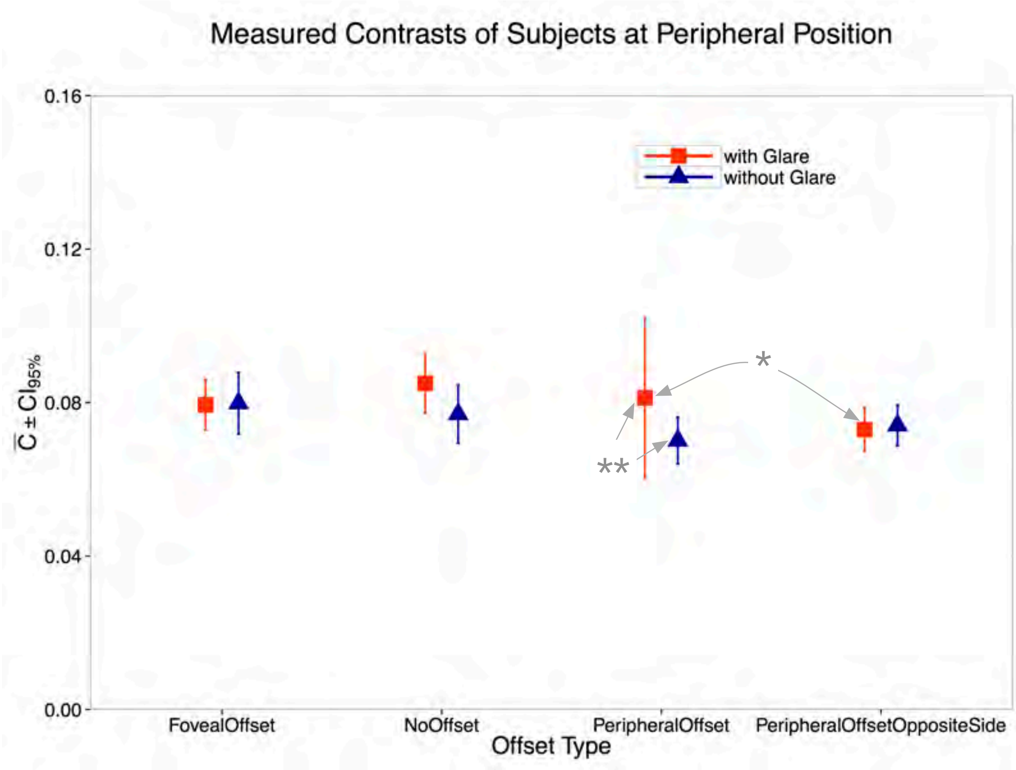


Figure 5: The measured contrasts at the peripheral position at 10° eccentricity for N=29 subjects. Significant differences are marked with stars.

The results of the measured contrasts for peripheral visual performance can be seen in figure 5. Again the reference contrast is offset type *NoOffset* without glare. The offset at the peripheral target position *PeripheralOffset* has no influence on the contrast compared to the reference, so don't the offset at *FovealOffset* and *PeripheralOffsetOppositeSide* do without glare.

The glare source is further away from the peripheral than from the foveal presentation point, therefore the influence on peripheral performance is less than on foveal performance, for all offset types. The contrast at position *PeripheralOffset* is increased highly significantly.

Statistical testing for significance was done using an ANOVA.

Table 2: The TI value calculated for $1\ \frac{cd}{m^2}$ and $6\ \frac{cd}{m^2}$.

k	Θ_k [°]	$E_k[lx]$	$L_{v,k}$ [$\frac{cd}{m^2}$]	$TI_{\overline{L_1}}$ [%]	$TI_{\overline{L_6}}$ [%]
1	2.88	0.5	1.21	92	22
2	4.87	0.5	0.21		

The calculated TI values can be seen in table 2. In order to assess the influence on foveal visual performance theoretically the TI value was calculated, once for the homogeneous background at $1\ \frac{cd}{m^2}$ with *NoOffset* and once assuming that local offset is changing the adaptation state to $6\ \frac{cd}{m^2}$.

4 Discussion

The three assumptions have proven to be valid:

1. Visual performance seems to depend on local adaptation when no glare is present. The foveal contrast threshold decreases significantly when adding a 5° $5\ \frac{cd}{m^2}$ offset. Local offsets at the other positions have no influence without glare.

2. Glare has an impact on visual performance for *NoOffset*. Our results show an increment of $46\ \%$, whereas the TI formula predicts an increment of $92\ \%$ for the foveal target position. The peripheral target position is less influenced, because it is further away from the glare source.

3. The impact of glare on foveal visual performance is reduced significantly if a brighter area is within the visual field. For the *FovealOffset* position glare has no impact at all. The assumed transferability of the local adaptation state to the TI formula does not seem to work. Whereas the TI formula predicted an increment of $22\ \%$, we could only find an increment of $4\ \%$.

The influence on peripheral performance is completely different. The offset on the peripheral target position *PeripheralOffset* without glare has no statistically proven impact (although the contrast is slightly reduced compared to the other offset parameters). Glare has an impact, but much less, and only at the *PeripheralOffset* position (see below for further discussion). We cannot give any reasonable argument for why the contrast for *PeripheralOffsetOppositeSide* with glare is significantly differing from the contrast at *PeripheralOffset* and assume this is just by chance.

Further research has to be undertaken in order to investigate the influence of varying the offset size, the offset luminance, spectrum and the homogeneous background luminance on the presented interactions.

The light of the foveal offset position was partly on the glare source (mainly around the right LED, see figure 2b). Whether that constellation (increased luminance around the glare source) has an impact on physiologically perceived glare / visual performance can't be clarified from this investigation and needs to be further researched. The fact that there is no influence on foveal and peripheral visual performance for *FovealOffset*, but a statistical significant increase of the contrast for peripheral vision at the *PeripheralOffset* position might be a clue that the increased luminance around the glare source has an impact on physiological glare.

5 Conclusion

To get back to the adaptation state required for CIE:191 we conclude the follwing for car drivers: typical street lighting scenes are not homogeneous. Glare has an influence on the adaptation state, so do inhomogenities. We have seen negative and positive influences in the results. If we assume the driver of a car has the headlights switched on (*FovealOffset*) the foveal visual performance improves and glare has no impact. There is no impact on peripheral visual performance with and without glare (compared to when taking the car headlights *FovealOffset* as reference). That means visual performance is even better than expected when taking a homogeneous background luminance into account. Therefore the background luminance of the street surface seems to be a good predictor for the adaptation state, without requiring to take glare or other inhomogenities into account. The impact of road lighting installation has to be further researched on that described situation.

6 Acknowledgements

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