Pedestrian Detection with Halogen, Xenon and LED Headlights: The Light Scattering Effect

Dipl.-Phys. Annika Kortmann[1]*, Dr. rer. nat. Tim Hoger[1]

[1]Ing.-Büro Schimmelpfennig + Becke, Germany

Corresponding author; email: kortmann@ureko.de

Abstract

Drivers' ability to detect pedestrians depends not only on the power and "range" of their headlights, another important factor is "light scatter". Can pedestrians be detected more quickly with more expensive Xenon and LED headlights than they can be with low-cost Halogen headlamps? Is it possible to bring about a significant improvement by changing the bulbs in Halogen headlights? With the aim of answering these questions, light tests were carried out using an Audi A4 with Halogen, Xenon and LED lights and with a variety of bulbs in the Halogen headlights. The results are compared with the outcome of a test involving a Series 1 BMW. Now it is possible to analyze whether pedestrians are easier to detect with Xenon or LED systems than with Halogen headlights. The results clearly demonstrate the limits of new headlight designs and the need for adaptive lighting systems.

Fußgängererkennbarkeit bei Halogen-, Xenon- und LED- Scheinwerferlicht: Der Streulichteffekt

Die Erkennbarkeit eines Fußgängers ist für einen Pkw-Fahrer nicht nur mit der Lichtstärke und der "Reichweite" seines Scheinwerfers verknüpft. Von Bedeutung ist auch das „Streulicht" des Scheinwerfers. Lassen sich Fußgänger mit höherpreisigen Xenon-und LED-Scheinwerfern früher erkennen, als dies mit kostengünstigen Halogenscheinwerfern der Fall ist? Ist es möglich, durch Austausch der Leuchtmittel in Halogenscheinwerfern eine wesentliche Verbesserung zu erreichen? Zur Klärung dieser Fragen wurden lichttechnische Untersuchungen mit einem Fahrzeugtyp (Audi A4) in der Halogen-, Xenon- und LED-Ausstattung durchgeführt, Halogenscheinwerfer mit verschiedenen Leuchtmitteln bestückt und die gewonnenen Ergebnisse der Untersuchung eines 1er-BMW gegenübergestellt. So lässt sich untersuchen, ob Xenon- oder LED-Systeme bei der Fußgängererkennbarkeit einem Halogenscheinwerfer überlegen sind. Die gewonnenen Ergebnisse zeigen die Grenzen der neuen Scheinwerfersysteme auf und die Notwendigkeit einer adaptiven Lichtregulierung.

Introduction

Nowadays most car headlights work with Halogen headlamps. Increasingly, newer, more expensive cars are equipped with Xenon or LED headlights. Amongst other things, it is claimed that they improve illumination and provide better light quality which are said to contribute to better road safety [1].

In 2016 ADAC tested LED headlights of six SUVs in terms of illumination, light quality, glare and adaptive light systems [2]. Tests were carried out in a *Lichtkanal* light system, on a test track and during a test drive. One of the things assessed was the homogeneity of light distribution, i.e. appearance of bright spots and irritating light flares. Conclusion: The LED lighting system with (amongst other things) good to very good “illumination” provides more safety compared to Halogen light.

Up to now there have only been few analyses of typical accidents in the dark with new lighting systems. In the last five years on average 550 pedestrians died in road traffic accidents in Germany [3], 23% died at night [4]. On the one hand assessing the role lighting systems in accidents is important for accident reconstruction and settling liability claims. On the other hand looking at an accidents involving a pedestrian and a car with Halogen lights and comparing it with Xenon or LED headlights could provide valuable information for on-going developments of headlight systems.

Those who own a vehicle which has “only” Halogen headlights and want to upgrade can find a variety of solutions on the internet. In addition to very bright, road legal bulbs there are also LED headlights with H7 fit. Osram for example offer their Night Breaker Unlimited which claims to provide optimum light for longer reaction time. In a bulb test, ADAC [5] assessed light quality and intensity, glare and bulb life. What is still missing is an assessment of whether objects can be more easily detected using different types of headlamps and as such really allow the driver more time to react.

Decisive in terms of accident reconstruction for court proceedings is whether there is consideration in favour of or against the vehicle driver when standard lighting is assumed. Was the pedestrian crossing the path of the car visible to the accident driver at an earlier stage due to having perhaps exchanged standard headlamps for “brighter” ones? In this case using a reference car with standard headlights as part of a photometric investigation would lead to incorrect results.

Basics of a photometric investigation

The luminance difference between pedestrian and background is measured in [cd/m²] in order to determine whether a pedestrian could have been detected. Luminance is the intensity of light emitted per unit area in the direction of the eye. When evaluating what is visible the measured luminance difference is compared and contrasted with the required threshold luminance difference according to Berek [6] and Adrian et al. [7]. Threshold luminance describes the luminance difference between an object and its background at which the object can still just be detected by a focussed observer under lab conditions.

The graph on the right in Figure 1 (Berek curves) depicts how the size of the object (visual angle) relates to the ambient luminance. In real life the visual impression of moving objects must be processed at speed. At the same time the driver is distracted by surrounding light sources. So-called adjustment factors take this into consideration. According to Schmedding et al. [8] the luminance differences measured on site in relation to the pedestrian‘s distance to the vehicle can be depicted in a “target vs actual chart“.

An example of a target vs. actual chart is given on the right in Figure 1. It shows that the pedestrian was first visible at a distance of just under 55 m. At this distance the measured luminance difference (red circles) is greater than the luminance difference required for detection which was given an adjustment factor of 3 (red line). Due to the selected increment of 13.9 m between pedestrian positions it was not possible to determine the detection distance more accurately by way of technical measurements. It can only be interpolated in conjunction with a continuous curve.

Luminance at the accident site and the visual impressions can be recorded using a luminance meter or a standard SLR camera. Measurements with a luminance meter can only be done point by point which makes light tests rather time consuming. By contrast when documenting the visual impression with a digital camera there is a problem with over or under-exposing the images so that detection of the pedestrian cannot be derived from a later review of the images.

Digital cameras and luminance meters have a similar set-up. Hence, Wüller [9] and Hoger [10] developed a method which allow using of a digital camera for photometric investigations. By calibrating the digital camera for a given aperture, length of exposure and ISO value it is possible to assign a luminance value to the brightness of the recorded image. The calibration also takes the light sensitivity of the eye (which depends on the wavelength) into account. The recorded images can be analysed using a PC.

Method

In order to determine detection of the pedestrian light tests were carried out during which a pedestrian approached from the left and from the right with a speed of 5 km/h at 90° to the vehicle's longitudinal axis. It was assumed that the car was travelling at a constant speed of 50 km/h and that the impact took place in the middle of the bonnet. In order to be able to reproduce, as faithfully as possible, the positions of pedestrian and car with different vehicles it was decided only to move the pedestrian towards the car. The distances to the collision site between car and pedestrian are shown in Table 1.

	Entfernung zum Kollisionsort (s=0m) [m]	
Zeit [s]	50 km/h (Pkw)	5 km/h (Fußgänger)
-1	13,9	1,4
-2	27,8	2,8
-3	41,7	4,2
-4	55,6	5,6
-5	69,4	6,9

Table 1: Car to pedestrian positions for photometric investigation.

(Entfernung zum Kollisionsort – distance to collision site, Zeit – time, Pkw – car, Fußgänger – pedestrian.)

In addition to the photographs depicting what can be seen from the car, each series of measurements determined the illuminance on the ground at 10 m increments along the extension of the vehicle's longitudinal axis up to a distance of 100 m and a photo of the headlight profile was taken from a height of 5 m. In each series of measurements a calibrated digital camera took photographs of the view from the car to the pedestrian at the intervals between 5 and 1 s before collision with the pedestrian approaching from both the left and the right. Figures 2 and 3 show views from the Audi A4 vehicles with standard H7, Xenon and LED headlight systems over a period of 4 to 1 s before impact with the pedestrian approaching from the right (Fig. 2) and from the left (Fig. 3). The visual impression for 5 s before impact was omitted as the pedestrian could no longer be detected due to the distance to car.

Results

The Audi's headlight profile is almost symmetric and elongated while the BMW comes with a classic asymmetric headlight profile. This can be derived, amongst other things, from the detection distances in relation to car model and illuminant (see Fig. 4 by way of an example). The angle width of the BMW's beam is clearly wider than the Audi' and hence the "range" smaller. This can be seen in Figure. 5 which depicts photographs at height as false colour images. Pedestrians coming from the right can be detected by standard Audi headlights at a distance of 44 m and by BMW headlights as early as 60 m.

There is no general rule as to which headlight profile is more beneficial. It largely depends on the speed, the clothing of the pedestrian and the point of contact at the car. Generally speaking the lighting profile should be adapted to the speed of the vehicle which can be achieved using adaptive lighting systems.

Photometric investigations show that detecting objects with Halogen headlights outside the near field is achieved through light scatter, and not direct illumination. This allows early detection of a pedestrian wearing light coloured clothing on the upper body. It is generally referred to as the "light scatter effect".

When comparing illuminants it turns out that non-road-legal LED lamps do not meet the requirements for headlight design. The headlight profile is distorted and blinds on-coming traffic. The Osram bulb with the highest illuminance in the near field showed an at best equal, if not worse detection of pedestrians when compared to a standard bulb. This might be due to over exposure of the near field and the ensuing problems for the eye to adjust. The Philips bulb was shown to have the longest detection distance. However, the left area of the beam is widened, irrespective of the vehicle. Tests should be done to ascertain whether gains in detection distance might be offset by causing more glare to oncoming traffic.

Changing the illuminant in the Halogen headlight can achieve an additional pedestrian detection distance of up to 8 m. The different headlight types (Audi and BMW) tested showed differences of up to 20 m in detection distance.

It follows that as part of light tests identical types of headlights must be selected, and, if possible, the illuminant should also be taken into consideration. However, central to determining detection distance is the speed of approach, the clothing of the pedestrian and the local circumstances.

The more sophisticated the headlight technology the wider is the illuminated area in the near field region. Xenon and, in particular, Halogen headlights as used in the Audi A4 B8 have a more symmetric headlight profile. By contrast the direction of the LED headlight profile is clearly asymmetric and pointing to the right (Fig. 6) so that the measured illuminance at a distance of 70 m from the front of the car is smaller than 1 lx along the longitudinal vehicle axis compared with an illuminance of 3 to 5 lx for Halogen and Xenon headlights.

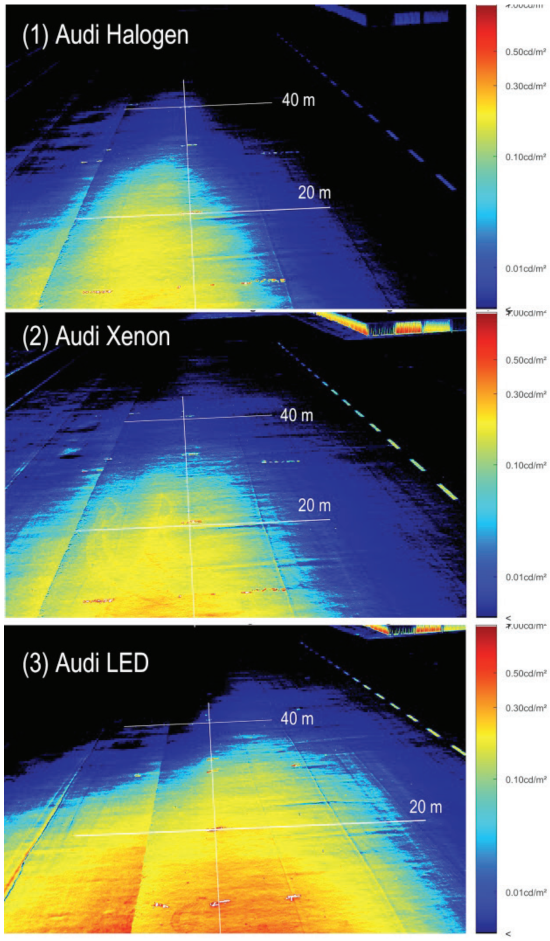

Fig. 6: Log. false colour images of Halogen (1), Xenon (2) and LED (3) headlights profiles.

Despite a wide beam angle Xenon and LED headlights can achieve a considerable "range" due to their high luminous flux. Pedestrians approaching from the right can be detected at a distance of as much as 70 m by Xenon headlights. For LED and Halogen the limit for detection is 56 m and 44 m respectively (Fig. 8). The capability to detect pedestrians approaching from the left is considerably reduced for Xenon and, particularly, LED headlights in order to avoid blinding on-coming traffic. Using Halogen bulbs pedestrians approaching from the left can be detected as much as 42 m away from the car compared with lower detection distances of 38 m and 27 m for Xenon and LED bulbs.

Comparing and contrasting the visual impressions of the pedestrian from the car and looking at the limit to detection by upper body and legs it is clearly evident that the headlights' light scatter portion became less and less when comparing Halogen, Xenon and LED headlights (Figures 9 and 10).

Fig. 9: Images of what can be seen from the Audi with Halogen, Xenon and LED headlights with the pedestrian approaching from the right between 4 and 1 s before impact.

This leads to a more clearly defined cut-off line between light and dark[1] and ultimately to cutting out upper body detection as detection is mainly governed by illuminating the pedestrian's legs. Using a computer we determined the absolute values for upper body luminance for each headlight type. The results are shown in Figure 11.

Fig. 10: Images of what can be seen from the Audi with Halogen, Xenon and LED headlights with the pedestrian approaching from the left between 4 and 1 s before impact.

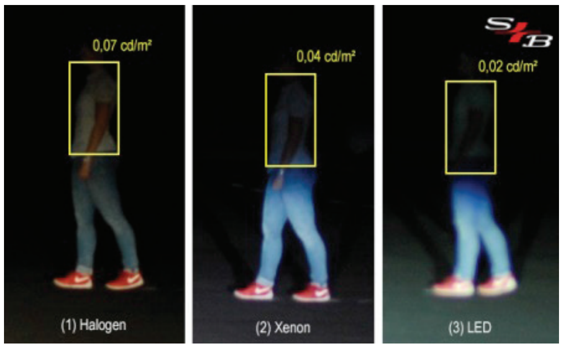

Fig. 11: Luminance in the area of the upper body at a 30 m distance with Halogen (1), Xenon (2) and LED (3)

Luminance continues to decrease starting with Halogen (0,07 cd/m²), then Xenon (0,04 cd/cd²) then LED (0,02 cd/m²), and as such the upper body is less and less illuminated.

[1] The line between directly lit and unlit area. For a standard car the angle of inclination of the headlights' cut-off line should be 1%. Accordingly at a 10 m distance the low beam dips by 0.1 m.

Reflective clothing and traffic signs can still be detected easily at longer distances even when using low scatter LED headlights (Fig. 12). In the tests we used a Mercedes E-Class T-Model (S212) with dipped headlights and took photographs of the view from the car to a pedestrian wearing a high visibility jacket with reflectors (Fig. 13) at 10 m increments from the front of the car along the longitudinal axis. Reflection is sufficient for detection up to a distance of 120 m.

Fig. 13: High visibility jacket with reflectors.

Light scatter only significantly contributes to pedestrian detection in the case of Halogen headlights. For Xenon and LED headlights pedestrian detection needs to be improved using adaptive light systems. With a speed-related lighting profile and a glare-free main beam such headlights can also detect pedestrians approaching from the left at greater distances which makes them clearly superior compared to traditional Halogen headlights. However, glare-free main beam is usually not used in built-up areas but this is where most accidents involving pedestrians happen. Hence new headlight systems do not provide an advantage over traditional Halogen headlights when it comes to pedestrian detection in built-up areas.

Therefore, investigation of new headlight systems using Xenon and LED shows that from a technical point of view adaptive systems are required in order to guarantee better pedestrian detection in built-up areas. The use of adaptive lighting systems will make it necessary to access vehicle electronics in order to reproduce dynamic changes in light during vehicle approach in future photometric investigations.

For detailed information regarding the light tests and their analysis please refer to the article published in the German technical magazine *VKU* (*Verkehrsunfall und Fahrzeugtechnik*) [11,12].

References

[1] ADAC (Article, 18. 10. 2016).

[2] ADAC, LED-Lichtanlagen von sechs SUVs im Test, www.adac.de (2016)

[3] Deutscher Verkehrssicherheitsrat, Getötete bei Verkehrsunfällen, www.dvr.de (2016)

[4] Deutscher Verkehrssicherheitsrat, Das Unfallgeschehen bei Nacht, www.dvr.de (2016)

[5] ADAC, Finger weg: Diese Glühlampen brennen zu früh aus, www.focus.de (2013)

[6] M.Berek, Zum physiologischen Grundgesetz der Wahrnehmung von Lichtreizen, Instrumentenkunde 63, 297 (1943)

[7] W.Adrian, Die Unterschiedsempfindlichkeit des menschlichen Auges und die Möglichkeit ihrer Berechnung, Lichttechnik 21, 2 (1943)

[8] K.Schmedding, M.Becke, Das SBU-Diagramm und die Bestimmung von Erkennbarkeitsentfernungen mit Hilfe des SI-Diagramms, VKU 28 (1990)

[9] D.Wüller, SLR Cameras for Luminance Measurements in the Mesopic Range, 18. EVU Conference, Hinckley, 2009.

[10] T.Hoger, Lichttechnische Untersuchungen mit einer Standard-Digitalkamera, VKU 52 (02/2016)

[11] A.Kortmann, T.Hoger, Fußgängererkennbarkeit mit Halogen, Xenon und LED: “der Streulichteffekt“ (Teil 1), VKU 1/2017

[12] A.Kortmann, T.Hoger, Fußgängererkennbarkeit mit Halogen, Xenon und LED: “der Streulichteffekt“ (Teil 2), VKU 3/2017

Full-width figures

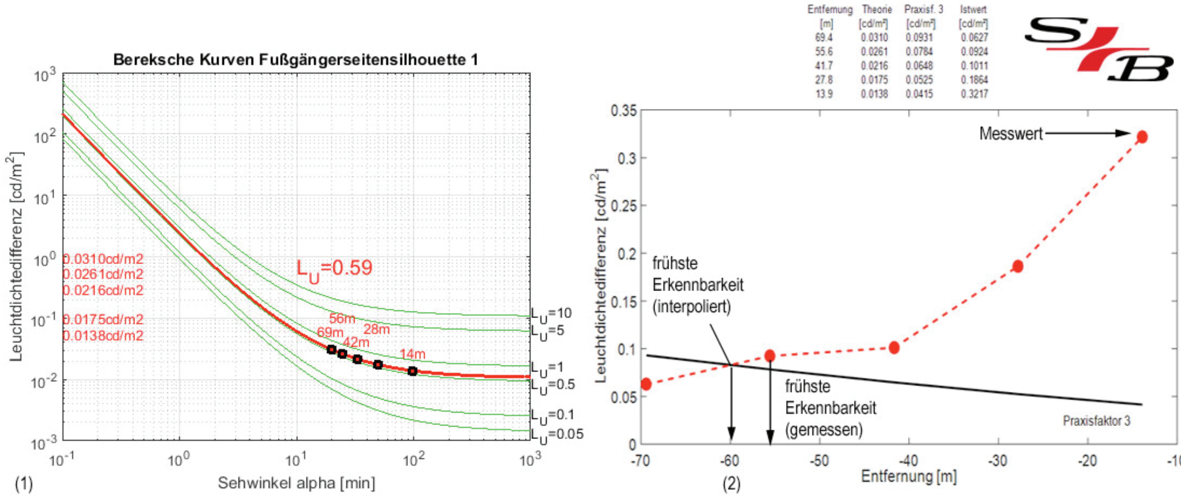

Fig. 1: Berek curves (1) and target vs. actual diagram (2) for analysis of the photometric investigation.

Bereksche Kurven Fußgängerseitensilhouette	Berek curves pedestrian side silhouette
Leuchtdichtedifferenz	Difference in luminance
Sehwinkel	Visual angle
Entfernung	Distance
Theorie	Theory
Praxisf.	Adjustment factor
Istwert	Actual
Leuchtdichtedifferenz	Difference in luminance
Frühste Erkennbarkeit (interpoliert)	Earliest detection (interpolated)
Frühste Erkennbarkeit (gemessen)	Earliest detection (measured)
Praxisfaktor	Adjustment factor

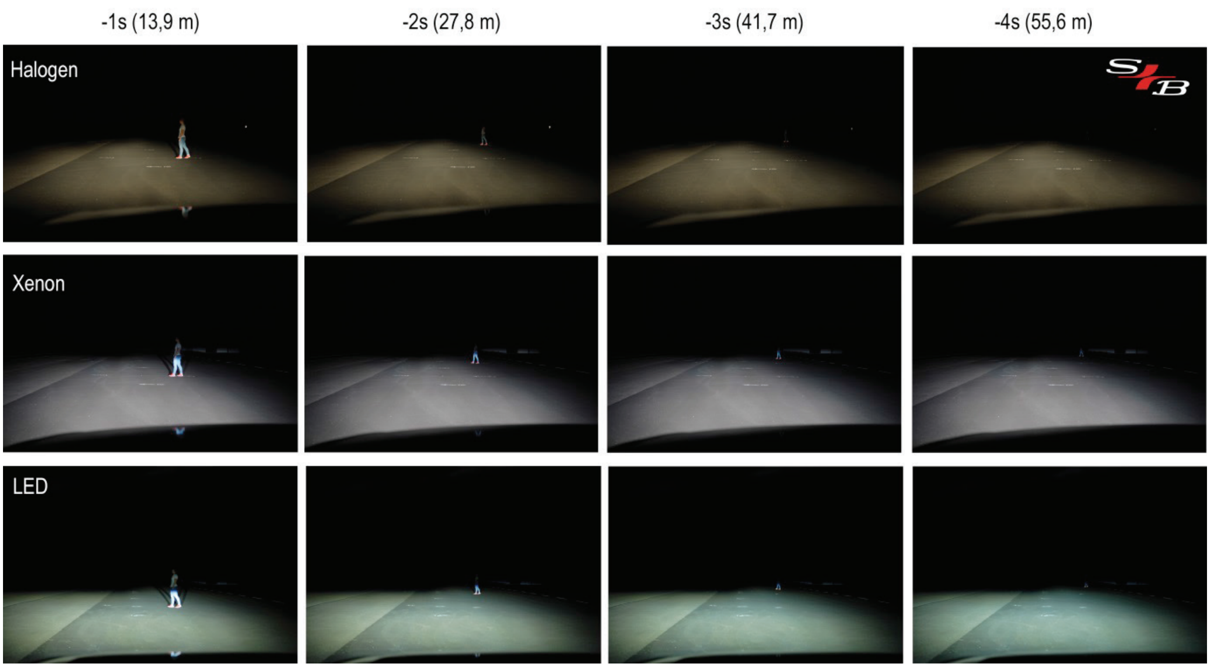

Fig 2: Photographs of what can be seen from the Audi with Halogen, Xenon and LED headlights with the pedestrian approaching from the right between 4 und 1 s before impact.

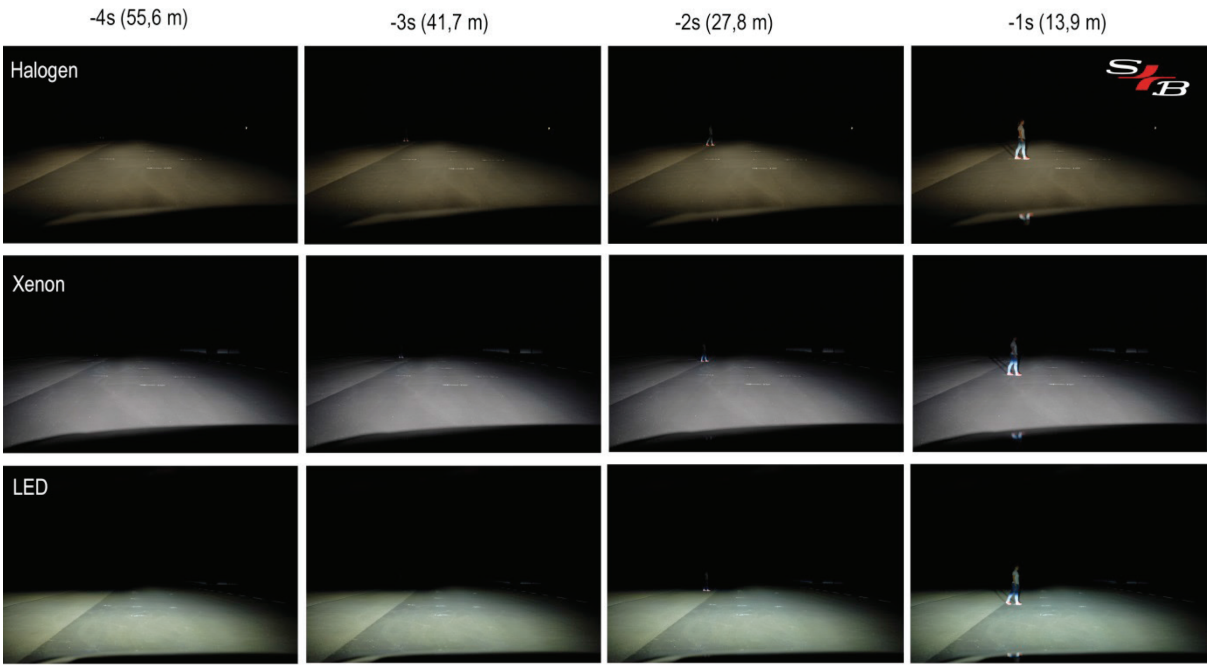

Fig. 3: Photographs of what can been from the Audi with Halogen, Xenon and LED headlights with pedestrian approaching from the left between 4 and 1 s before impact.

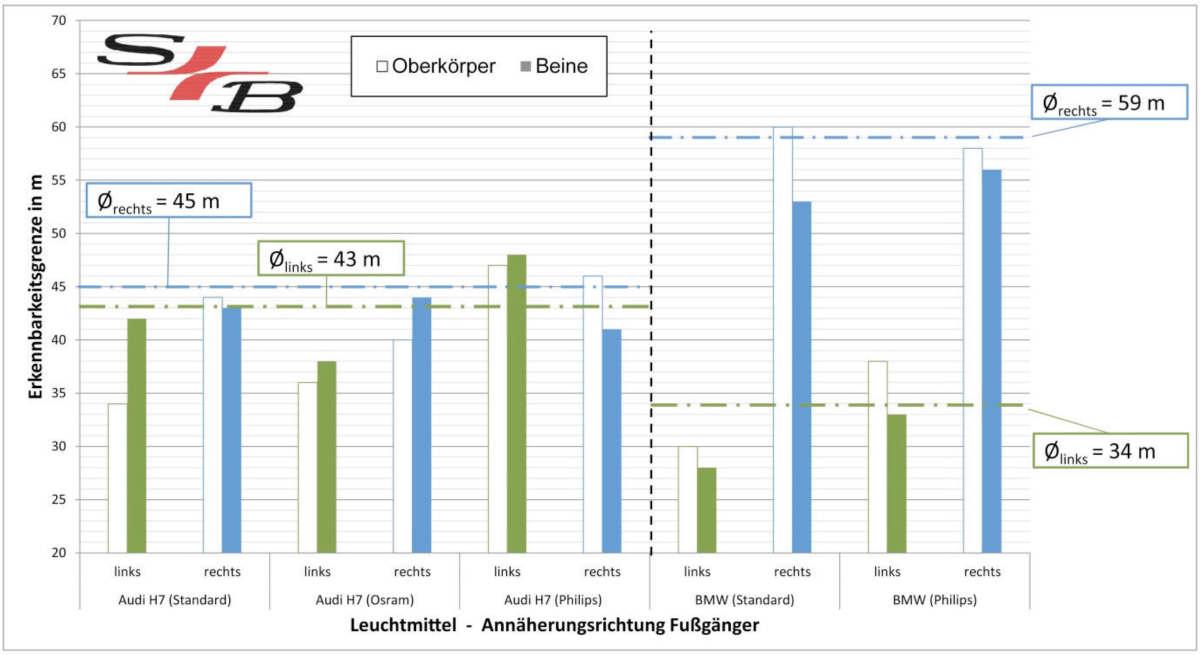

Fig. 4: Ability to detect pedestrians in relation to vehicle model and illuminant.

Oberkörper	Upper body
Beine	Legs
Erkennbarkeitsgrenze	Detection limit
Leuchtmittel – Annäherungsrichtung Fußgänger	Illuminant – Pedestrian´s direction of approach pedestrian
Links	left
Rechts	right

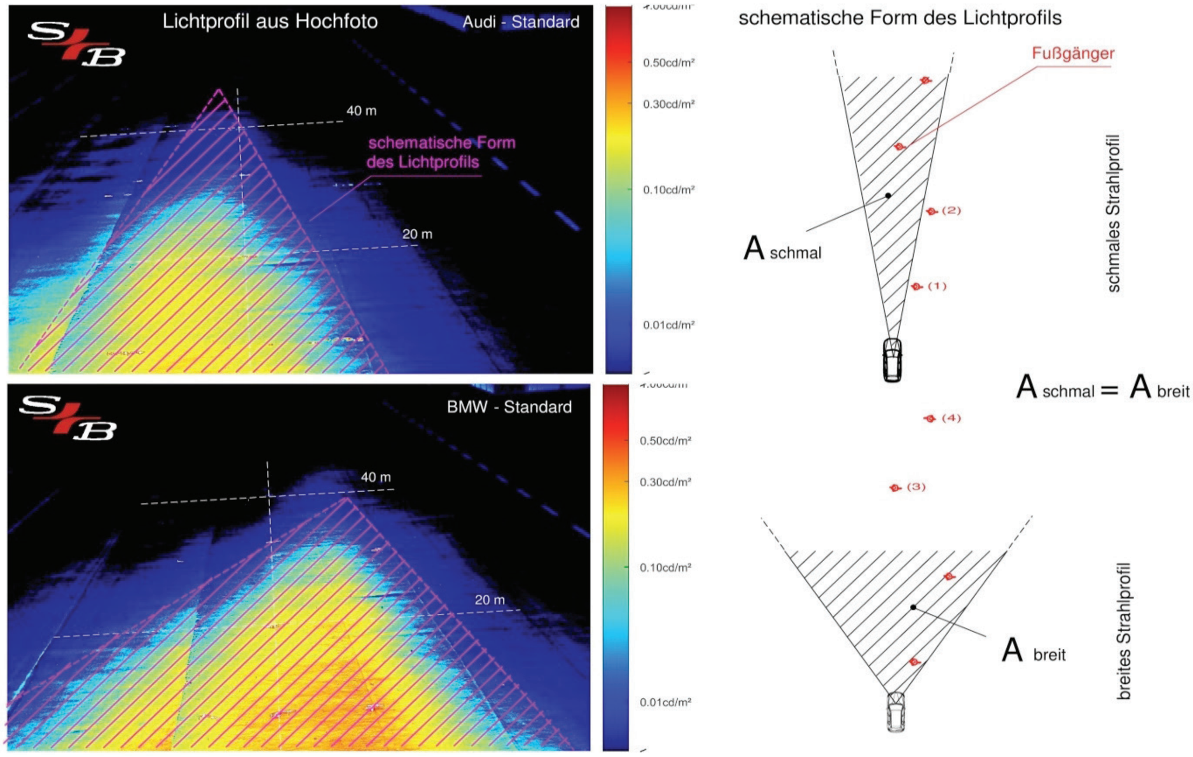

Fig 5: Relationship between the schematic shape of the light profile and the ability to detect pedestrians.

Lichtprofil aus Hochfoto	Light profile from high-up photo
Schematische Form des Lichtprofils	Schematic shape of light profile
Fußgänger	Pedestrian
schmal	narrow
breit	wide
schmales Strahlprofil	narrow beam profile
breites Strahlprofil	wide beam profile

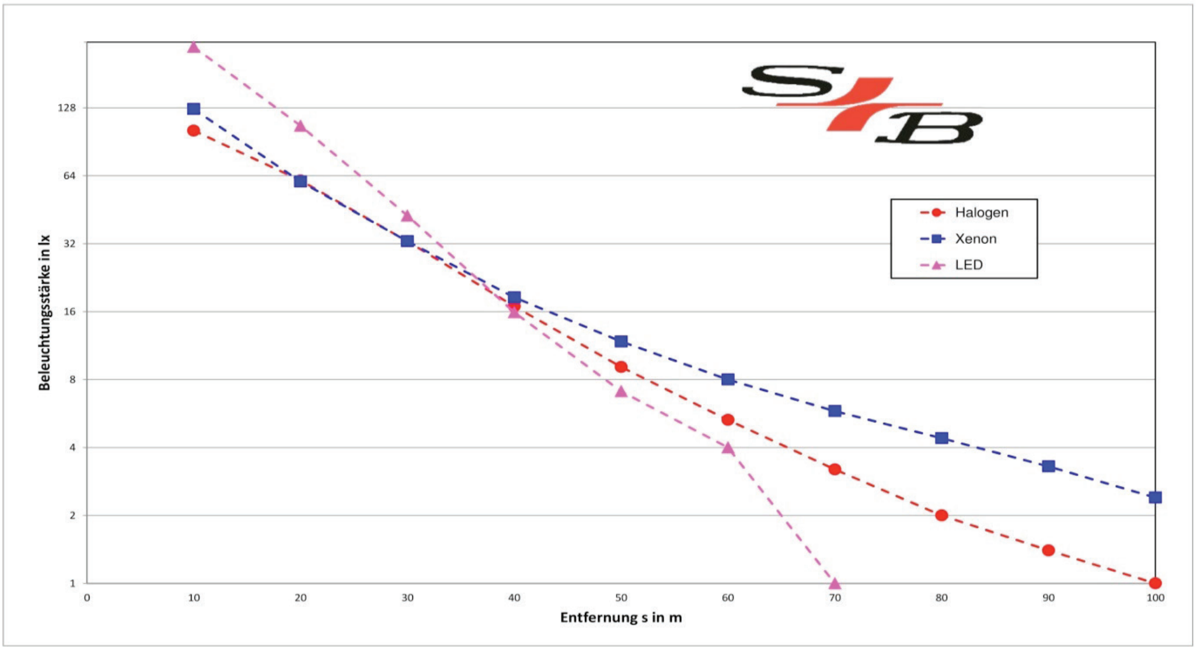

Fig.7: Illuminance curve with Halogen, Xenon and LED.

Beleuchtungsstärke	Illuminance
Entfernung	Distance

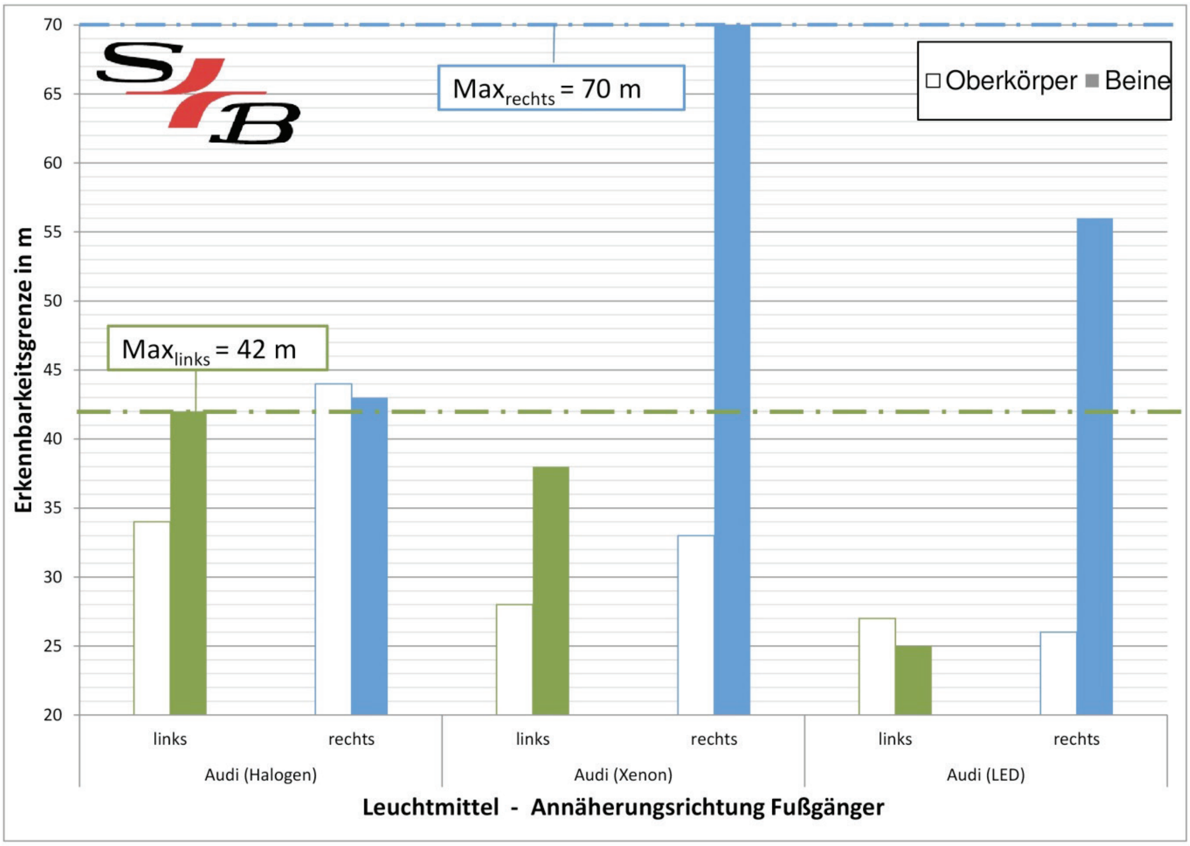

Fig 8: Ability to detect pedestrians relating to the illuminant (Audi).

Erkennbarkeitsgrenze	Detection limit
Leuchtmittel – Annäherungsrichtung Fußgänger	Illuminant – Pedestrian´s direction of approach pedestrian
Max links	Max left
Max rechts	Max right
Oberkörper	Upper body
Beine	Legs

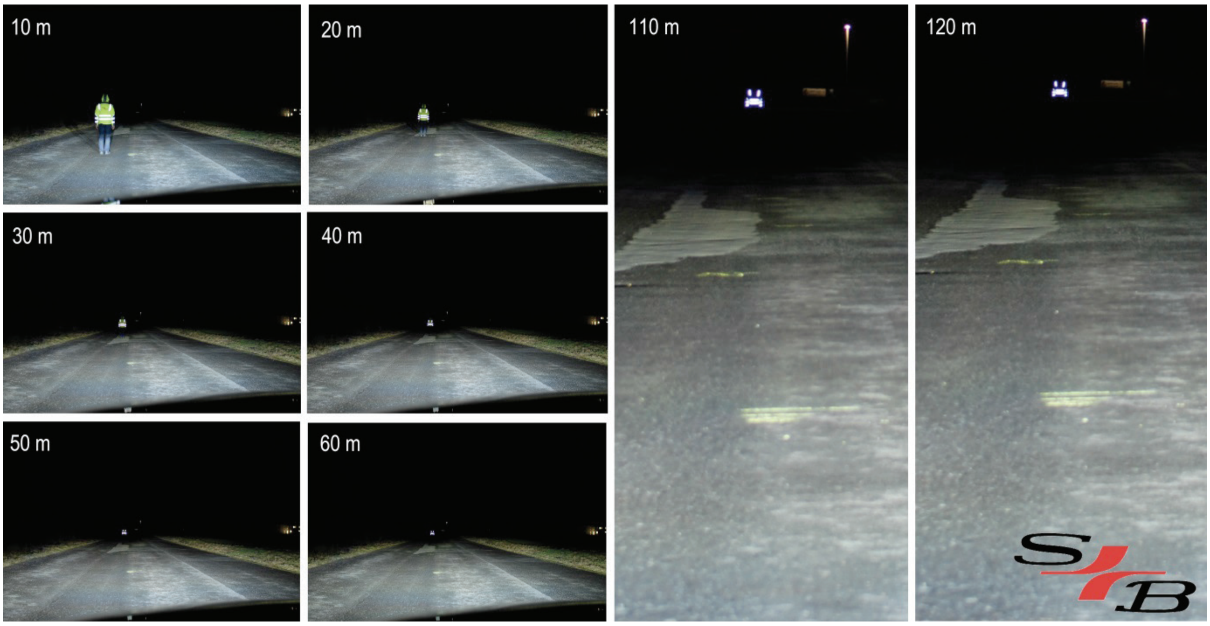

Fig. 12: Visual impression of the pedestrian from a Mercedes with LED, headlights (dipped).