Recognition of retroreflective road signs during night driving

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Temporal waveforms of the illumination at the driver eyes position were determined in various night traffic and weather conditions (ideal weather and correct aligned lights as compared with dirty lamps and raindrops on the windscreen). The statistics of retinal illumination were analysed, and a computer controlled technique was developed to simulate similar changes of eye illumination. The participant fixated on retroreflective optical stimuli at a distance of 5 m. The participant was then subjected to dazzle, and recovery from the glare took place. The background illumination was in the mesopic range. Experiments showed that at background illumination 0.1 Lx no dazzling took place in case of correctly installed clean headlights. The participant was dazzled if the high beam lamps were incorrectly aligned or cycloplegia was used for pupil dilation. The dazzle time depended on the background illumination level and could increase to three seconds for the illumination changes corresponding to the equivalent speed of vehicles 50 km/h.

Introduction

Vision plays a significant role in safe driving. Standards for vision must be met for a driver to hold a licence. These standards prescribe the vision quality in normal situations with sufficient illumination levels. Driving at night is a more difficult task (Charman, 1996; Priez *et al.*, 1998), more accidents per vehicle happen on roads at night (Federal Office of Road Safety, 1996). Many measures have been undertaken to ensure safe driving at night. These include optimal road design and marking, sufficient illumination of difficult road segments, and optimum car headlight construction to provide sufficient visibility without dazzling oncoming car drivers.

Many aspects of driver vision make the task of driving at night difficult. These include lower and non-uniform illumination, a smaller ratio between visibility and braking distance, decreased visibility during rain, less reflection from the roadbed, and refracted and scattered light from the windscreen. At high adaptation levels (during the daytime - photopic vision) cone type photoreceptors dominate perceptual input. They are placed with the maximum density in the central part of the eye retina – fovea. Cones ensure the high visual acuity of the central vision and the colour vision. They have relative low sensitivity, respond to the visual stimuli and adapt to

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illumination changes quickly. Cones are not so critical to momentary overexposure. At low illumination – rods dominate perceptual input. They are placed outside the central part of the retina, thus the visual acuity in scotopic conditions (eye pupil illumination level $A < 0.1$ Lx) is much lower. Night driving is at low luminance – in mesopic conditions (0.1-2 Lx), therefore vision involves rod function and possibly some cone function (Hart, 1992; Pitts, Kleinstein, 1993). The rod dominance in visual perception makes slower the stimulus response time, seriously increases the adaptation time and the recovery time after over-illumination (Bear *et al.*, 1996; Hubel, 1990). At low illumination night myopia occurs which causes an additional up to -1 diopter optical correction. This is a phenomenon when our visual system at night, in absence of visual stimuli, is not accommodating to infinity, but to a closer distance - about 1m. There is some evidence that this may not be a serious problem with night driving, but results are not conclusive (Charman, 1996).

Optimising car headlights and increasing lamp luminance can improve visibility on unlit roads. However, increased luminance increases the risk of dazzling oncoming drivers. Lamp construction and adjustment should minimise dazzling. Still a variety of unforeseen circumstances can take place: a non-compliant driver, who does not dip correctly car lights, an undulating road where at some moments car lights can be turned upward and toward the oncoming vehicle. Partial or full dazzling on unlit roads is the main reason for night driving discomfort. Bright visual stimuli lead to dazzle and to a temporary loss of visual perception ("dead" time). During this time, lane control can be impeded, and the response to a sudden emergence of an obstacle can be delayed.

The eye is partially protected from dazzle by pupil constriction. This normal reaction can be depressed in some cases either after using alcohol and drugs, or after a medical eye treatment, e.g., in the case of cycloplegia (Bogoslavsky, 1962; Bear *et al.*, 1996). Taking into account that the eye pupil changes its diameter d from 7-8 mm in dark to 2-3 mm in a bright environment (i.e., a change of the transmittance of more than one order), the depression of the normal pupil response to illumination change can seriously increase dazzling.

The spatial and temporal distribution of driver retinal illumination, when a vehicle passes with headlights switched on, is complicated. The lamps project light on the retina as light spots that move from the central to the peripheral retinal region while the car approaches. The luminous flux $\Phi = A \cdot (\pi d^2/4)$ reaching the retina increases. Illumination also increases, but remains fairly constant at individual photoreceptors as the flux increase is counterbalanced by increasing of the area of the illuminated spots on the retina according to the inverse square low. These changes in luminous flux, retinal area stimulated and changes in retinal receptor density and population within these areas mean that dazzling is a complicated result of the visual stimuli response integrated in space and time.

The following factors affect dazzling in driver night vision:

- headlight design: their luminance, the illumination directionality and lamp adjustment;
- speed of the moving vehicles;
- eye adaptation level before the dazzling event;
- the pupil ability to respond to increased illumination;
- various side effects of narcotics or medicine that can change pupil response or overall visual response.

The objectives of the present study were: to build outdoor and indoor equipment that measures the dynamics of the driver eye illumination; to simulate “real world” conditions to study participants’ ability to recognise retroreflective signs at dazzling illumination levels for participants without eye pathology. Experiments were carried out according to the following scheme:

1. Acquisition of statistical data of driver eye illumination on dual carriageway roads.
2. Outdoor measurements of eye illumination in various simulated illumination conditions (ongoing car with switched on low beam, high beam, misaligned lights, with different types of light scattering cover layer, dirty lamps).
3. Indoor experiments that simulate dazzling with altering in time illumination in order to detect the participant’s ability to recognise retroreflective visual stimuli with simultaneous measurement of the eye pupil contraction.
4. Determination of the “dead” time when vision is depressed due to dazzling for participants without and with pupil response blockaded due to cycloplegia.

Method

In order to determine the histograms of the driver's eyes illumination, test-rides were performed on dual carriageway roads. The light sensor was attached to the windscreen at the height of the driver’s eyes. For data acquisition a TAOS *TSL230* light-frequency converter and a tape recorder inside the car were used (see Figure 1). The *TSL230* light-frequency conversion ratio can be set either using soft or hardware. The illumination data were extracted from the sound track (with frequency 10 Hz) using a simple PowerBasic program (data sampling frequency 30 kHz). Figure 2 shows a histogram of the maximum values of the pupil illumination when the headlights of the passing vehicles dazzle the driver.

Temporal waveforms of the driver's eye pupil illumination depending on lighting conditions of the oncoming vehicles also were measured. The illumination values were acquired inside the car at the level of the driver eyes at h = 1.22 m with a period of $\Delta t \approx 0.08$ s. A car passing at a constant speed of 20 km/h had either low or high beam headlights switched on (both lamps of tungsten-halogen H4 type 60/55W). The lamps were kept either correctly aligned according to the European standard, or slightly misaligned - lifting the light direction axis at the angle 1.4^{o} (Δh = 10 cm for the lamp spot on the screen at the distance 3 m). The lamps were kept clean, dirty, or covered with a plastic sheet to simulate the lamp icing.

The indoor experiments were carried out in the following way. For a glare light source, we used two stationary lamps in the car reflectors. The lamps were placed at the distance of 5 m from the participant symmetrical to the participant's gaze direction 1 m apart. The lamp luminance was controlled by a function generator producing single saw pulses and a MOSFET power amplifier in order to simulate the time dependence of the pupil illumination corresponding to the speeds 50 km/h for both cars.

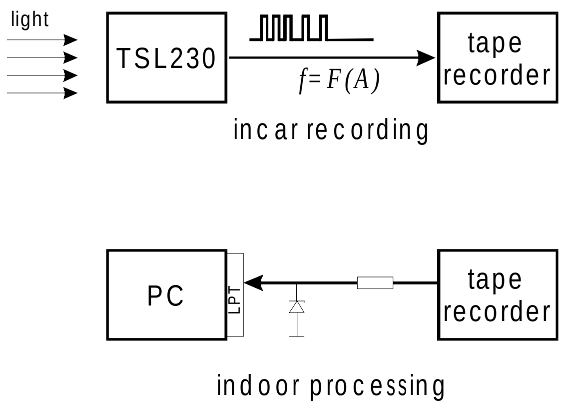

Figure 1. Experimental set-up for acquiring the driver eye illumination data.

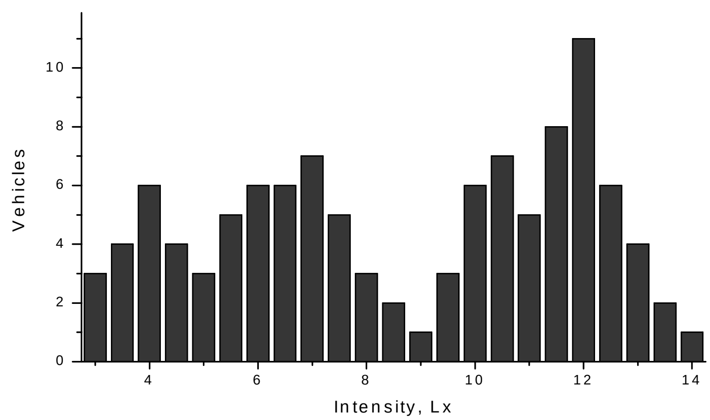

Figure 2. Histogram of the car driver's eye illumination.

For visual stimuli we have used two types of retroreflective objects. The first was a Snellen visual acuity letter E formed by black stripes glued onto a white retroreflective *ScotchLite* type sheet and a reverse polarity letter E stimulus. A third reflector was a letter E formed from red plastic cube retroreflectors on the black surrounding. The size of the stimuli was chosen so to correspond to the visual acuity VS = 0.5 (decimal). The stimuli were illuminated (A = 30 Lx - corresponding to the illumination level of low beam) with a small divergent light beam along the direction of the participant's gaze. The protocol of the measurements was there as follows. For each value of the background pupil illumination (0.1-3 Lx - mesopic conditions) the vision of the participant adapted within 5 min. After that, the dazzling lamp control was switched on. Simultaneously, the computer picked up the measured eye illumination. The participant's task was to fixate until t_l when he lost the stimuli placed at the distance 5 m, firstly; and after the lamp is switched off at t_o, to fixate until t_r he regained ability to recognise the stimuli, secondly. Three values were derived from the data: $t_1 = t_o - t_l$ - the span between loosing the stimuli and the switching off the dazzling light, $t_2 = t_r - t_o$ - the recovery time that equals to the span between the switching off and recognition time, and the "dead" time $t_d = t_1 + t_2$.

The response of the pupil was captured by an infrared (IR) CCD camera. The time dependency of the pupil constriction was extracted from the frames of the *.avi* file. The IR source was a LED (light power up to 40mW) with a light diffuser placed at a distance of 15 cm from the eye.

Results

Figure 3 shows the obtained eye pupil illumination over time for some oncoming car headlamp conditions. Measurements were carried out on an illuminated street. The illumination measured in the car at the position of the driver eyes depends on various factors. One of them is the side distance between cars passing by. We attempted to keep this distance at 1.5 m, similar to what is habitual on Latvian roads. The maximum illumination of the oncoming car driven with regular low beams was approximately 13 Lx, with regular high beams *approximately* 60 Lx. In Figure 3 data for high beam dazzling illumination and for low beam covered with textured plastic sheet are displayed as acquired. The background illumination AC component was of small amplitude (≈0.5 Lx). The periodicity of the background component - due to the interference between the main frequency and sampling frequency, allows easy extraction when processing data. Eye illumination time dependencies are complicated with additional maxima and minima. The maxima are probably caused by reflections from the bonnet, the minima due to shading by the car body design elements. In order to characterise these irregular dependencies we used the following parameters: the maximum value of the eye illumination $\boldsymbol{A_M}$, the total fluence during the illumination cycle $E = \sum_i A_i \Delta t_i$ and the "half-width" of the illumination waveform $\Delta\tau_{E_{1/2}}$. The latter parameter equals the shortest time interval within the illumination cycle, within which the illumination produced the fluence $E_{1/2} = 0.5E$. Values of these parameters are given in Table 1. These data confirm the influence of the different light directionality of the low and high beam with or without diffusers on the values of $\Delta\tau_{E_{1/2}}$. The high beam has high intensity values for frontal directions. A fast decrease of the intensity occurs if the irradiation angles fan outwards. Due to the outstretched directionality of the high beam the resultant eye illumination increases slower as compared with a case of uniform directionality, when the inverse square law holds true.

The low beam has a more uniform directionality, and the increase of the illumination when cars are approaching occurs within a shorter time. Thus the "half-width" time $\Delta\tau_{E_{1/2}}$ values for the low beam are shorter compared with the high beam "half-width" time $\Delta\tau_{E_{1/2}}$. This is also the case when the $\Delta\tau_{E_{1/2}}$ values for the high beam decrease if additional scattering factors (plastic film, dirty lamps) are present.

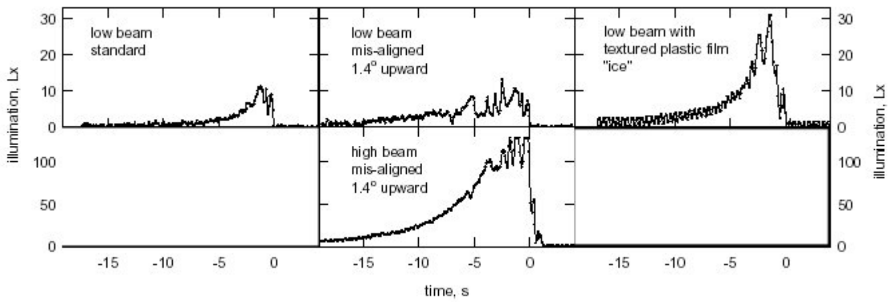

Figure 3. Time dependencies of the illumination in a car at the position of the driver eyes, when oncoming vehicle is passing with speed 20 km/h with different headlamps switched on and in different lamp conditions.

The driver eye illumination data in Table 1 show some trends. Simulated icing of headlight covers increased light at the driver's eye for both beam types. However, the diffusing factor, mud decrease illumination at the eye caused by the high beams.

Table 1. Driver eye illumination "half-width" time $\Delta\tau_{E1/2}$, maximum illumination A_M and illumination caused eye fluence E for different conditions of the oncoming car headlamps (speed of vehicles V_1 =0, V_2 = 20 km/h).

	$\Delta\tau_{E_{1/2}}$,s	A_M, Lx	E , Lx·s
low beam standard	2.1	13	630
high beam standard	3.0	60	9100
low beam mis-aligned 1.5° upward	3.2	14	990
high beam mis-aligned 1.5° upward	3.4	130	18000
low beam with 1 mm plastic film "wet"	2.1	14	880
high beam with 1 mm plastic film "wet"	2.5	60	6400
low beam with textured plastic film "ice"	1.9	32	1500
high beam with textured plastic film "ice"	2.3	75	6500
low beam "muddy"	1.8	18	850
high beam "muddy"	2.8	40	3600

In the indoor experiments we could not duplicate exactly the same eye illumination waveform with shading and reflexes. However, we used as criteria the “half-width” time $\Delta\tau_{E_{1/2}}$ and the maximum value of illumination $\boldsymbol{A_M}$ (Figure 4). In preliminary experiments we ascertained that participants lost the ability to see visual stimuli only at illumination levels of high beam lamps. Therefore, we used two $\boldsymbol{A_M}$ levels possible in some unfavourable cases: 110 Lx that corresponds to illumination with correctly aligned lamps and 240 Lx - to poorly aligned headlamps. Three subjects participated in experiments. All participants repeated the test 10 times. Tests were also carried out with participants before and after administration of cycloplegic eye drops. Results of these experiments are shown in Figure 5 and summarised in Tables 2 and 3.

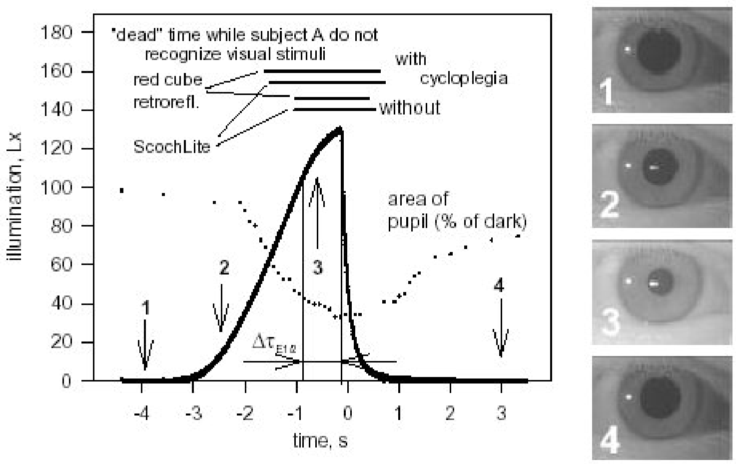

Figure 4. Time dependence of the dazzling illumination, corresponding to the vehicle speed 50 km/h., The dotted line shows shrinking of the pupil measured each 0.1s. Pupil pictures (captured at moments shown in figure with arrows) are shown at the left.

The temporal loss of the visual perception for high beams is greater on unlit roads and at low levels of street illumination. This illustrates the importance of dipping high beam lights. The recovery time t_2 of each participant varies little for different adaptation levels or dazzling conditions within the adaptation range 0.1-0.3 Lx. This time is the most critical for the driver because neither before dazzling nor during it the driver has any possibility to evaluate the risk of hitting an obstacle. The time period $t_1 = t_0 - t_l$ depends strongly on the dazzling illumination. Investigation under cycloplegia reveals longer loss of visual perception due to dazzling. At high eye illumination participants with dilated pupils can lose visual perception also at standard city street illumination.

Table 2"Dead" time t0 and recovery time t2 for three subjects to recognize the ScochLite type Snell E visual stimuli at various conditions of dazzling illumination.

Adaptation level →		0.1 Lx		0,3 Lx		1.9 Lx	
Dazzling conditions	Subject	t_0, s	t_2, s	t_0, s	t_2, s	t_0, s	t_2, s
110 Lx	A	1,5	0,5	1,5	0,5	-	-
	B	2.8	0,6	1.7	0.6	-	-
	C	2.6	0.7	0.74	0.2	-	-
240 Lx	A	3,1	0,65	1,9	0,5	-	-
	B	3.1	0.9	2.8	0.7	-	-
	C	2.7	1.0	2.5	0.5	-	-
110 Lx *Cycloplegia*	A	2,2	0,7	2,4	0,6	-	-
	B	2.3	0.7	2.7	0.8	-	-
	C	2.7	0.8	2.1	0.4	-	-
240 Lx *Cycloplegia*	A	3,2	1,1	2,8	0,75	1,4	0,3
	B	3.2	1.0	2.7	0.9	1.6	0.6
	C	3.3	1.1	2.45	0.6	1.5	0.3

Table 3 "Dead" time t0 and recovery time t2 for three subjects to recognize the red plastic cube retroreflective Snell E visual stimuli at various conditions of dazzling illumination.

Adaptation level →		0.1 Lx		0,3 Lx		1.9 Lx	
Dazzling conditions	Subject	t_0, s	t_2, s	t_0, s	t_2, s	t_0, s	t_2, s
110 Lx	A	1,4	0,4	1,6	0,3	-	-
	B	2.3	0,4	1.6	0.4	-	-
	C	2.0	0.5	0.3	0.2	-	-
240 Lx	A	3,0	0,6	1,8	0,4	-	-
	B	2.6	0.7	2.3	0.55	-	-
	C	2.4	0.6	1.8	0.4	-	-
110 Lx *Cycloplegia*	A	2,0	0,6	2,2	0,5	-	-
	B	1.9	0.6	2.4	0.5	-	-
	C	2.2	0.55	1.4	0.4	-	-
240 Lx *Cycloplegia*	A	1.7	0.7	2,6	0,7	-	-
	B	2.6	0.8	1.2	0.6	0.7	0.5
	C	2.8	0.85	2.1	0.4	1.2	0.3

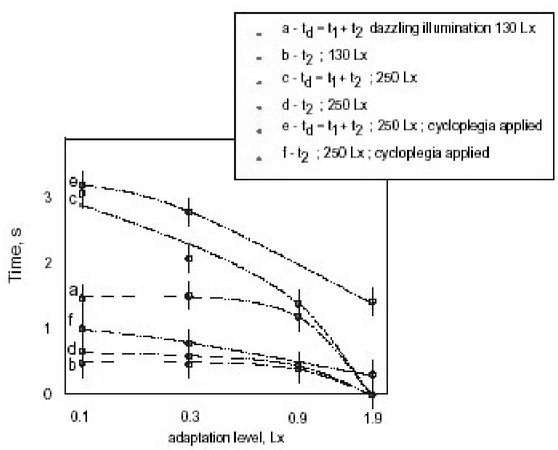

Figure 5 Time dependencies of the "dead" time td and recovery time t2 for subject A on adaptation level for various dazzling conditions and cycloplegical eye treatment.

Conclusions

An experimental technique to register the dynamics and the statistics of eye illumination of drivers was developed. Data were applied to indoor tests where similar dazzling conditions were simulated in order to determine the “dead” time when the driver loses ability to recognise visual stimuli. The “dead” time on unlit roads with adaptation level 0.1 Lx can reach 3 s for vehicles driving at a speed of 50 km/h without dipping high beams. Blocking the pupil constriction increases the “dead” time and the visual perception loss can be present also at higher street illumination levels. Comparing the effect of various designs of retroreflective stimuli some decrease of the “dead” time for cube retroreflector stimuli were revealed as compared with *ScotchLite* film reflectors.

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