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Visualization of disability glare due to veiling luminance

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Abstract

We present a simulation method to evaluate and visualize disability glare problems. Mathematical calculations of visual degradations due to optical imperfections in the eye are performed on luminance photos of scenes and the result is visualized. The method was evaluated in three indoor and outdoor cases where different visual aspects on disability glare were studied. Overall, the simulations predicted problem areas in the scenes to a large extent. The method was also applied in a light rendered 3D-model and gave indications for improvements of the light setting. Aspects on improving environmental planning by better understanding of human vision are discussed.

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Keywords: disability glare; simulation; visualization; light perception; visual assessment; visual performance; high dynamic range images

1. Introduction

Considerable resources are currently spent on making society more accessible to disabled people. A large group that is often excluded is people with moderate vision loss caused by normal ageing and disease. These people may very well meet the visual requirements for driving, but can still experience great difficulty in daily life [1]. For example, symptoms may arise in both indoor and outdoor environments with low levels of contrast in combination with intense light sources, a situation often caused by inappropriate design. When this phenomenon causes a degradation of the visual performance it is called disability glare [2]. This term is defined in CIE e-ILV 17-330: “glare that impairs the vision of objects without necessarily causing discomfort “ [3]. This is a rising problem due to

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the development of new light sources that often emits more intense light than traditional luminaires.

Normal ageing of the eye means that the eyes' optical media starts to absorb and scatter light as we grow older [4] and is the main cause of disturbances of vision seen in ageing people [5]. Scattered light in the eye causes a veiling luminance [6] that is superimposed on the retinal image, which reduces the contrast levels and is the main reason for disability glare. Therefore we focus our analysis on veiling luminance, as it is highly significant for visual impairment. It is easy to determine if a specific light source causes veiling luminance or not, by temporarily obscuring it with the hand. If the contrast in the view *increases* when the light source is obscured, it causes veiling luminance that immediately disappears when the light source is no longer present in the field of view.

When the opacification of the lens finally has reached a certain level, it is diagnosed as cataract. Then the biological lens preferably can be replaced with an artificial lens to regain vision. However, the opacification process is slow and many people are suffering from visual problems long before they are diagnosed and listed for surgery.

In this paper we will present a method that might help to improve the understanding of human vision and that scattered light in the eye causes disability glare. With the proposed method, it is both possible to visualize the visual scene like it might appear through someone else's eyes, and to calculate a simulation of the retinal luminance image that can be further analysed with regard to luminance levels and contrasts.

2. Visualizing disability glare problems

Evaluation of disability glare starts by estimating the veiling luminance in a particular scene for an observer. International Commission on Illumination (CIE) has proposed some methods mainly for traffic lighting applications. In the CIE report [7] the Threshold Increment (TI) method is proposed for analysing disability glare for road lighting installations at the luminance range 0.02-5 cd/m^2 on the road. The total veiling luminance on the retinal image is calculated by summing the veiling luminance contributions from all luminaires, i.e. road lights, in the field of view. The result is the TI number, that is a measure of the total veiling luminance. This has to be done for every viewing direction of the observer, but the standard procedure is for just one direction along the road.

Another CIE report [8] describes a method for determining the required lighting levels in the entrance zone of tunnels during daylight. The veiling luminance falling on the tunnel opening is calculated from a position about 70m in front of the tunnel. The brighter the areas outside the tunnel, the harder it is to see low contrast objects in the dark tunnel opening. This is not primarily an adaptation problem, because the veiling luminance from the strong daylight in the field of view is *superimposed* on a low intensity scene in the entrance zone of the tunnel. The same concept as for the TI calculation is used, but contributions from all areas in the field of view are summed up. When the veiling luminance is known, a preferred illuminance on the road inside the tunnel can be calculated.

Our method is based on the same concept as described above, but designed so it can be applied on a general viewing situation. First a luminance calibrated high dynamic range (HDR) photo is captured of the scene we want to analyse, so that all intensity levels are registered photometrically correct. The HDR photo is generated from a sequence of photos taken by a single lens reflex (SLR) camera c.f. [9]. Second, the veiling luminance in the scene is calculated by convolving the HDR image by the complete point spread function (PSF) of the eye [10] [11]. The result is an estimation of the light distribution on the retina. The visibility of any object in the scene can be analysed by measuring luminance contrasts in the this image. Generally speaking, the degree of disability glare is proportional to the contrast reduction in the scene caused by the veiling luminance contribution. To get a quick impression of the level of disability glare, we also calculate a visualization of the retinal image that resembles the visual impression of the scene and can be viewed on a computer screen or paper. This is basically a tone mapped version of the HDR image of the scene, c.f. [12]. If this visualization image has lower contrast than the original image, it is a sign that the veiling luminance is strong, and the risk for disability glare is high.

3. Indoor feasibility study

In a first test we evaluated the simulation method described above, in an indoor hallway with three light settings. We selected a small group of observers with impaired vision that we conducted in-depth interviews with about their experience of light and colour in the room. The visual performance of the observers under the different light settings was also studied. In this way, we got valuable indications about opportunities and weaknesses with the simulation method. We verified that the visualizations roughly agreed with the visual impressions from the observers and that the simulations of veiling luminance contributions to the scenes could predict visibility degradation.

The observers were 59 - 98 years old and had impaired vision due to normal ageing or cataract. One of the observers had one eye with cataract and one with normal aging, which made her a particularly valuable observer. The observers assessed the perception of light and colour, as well as performed contrast sensitivity tests in three different lighting scenarios. The light setting scenario1-3 are shown in Fig. 1a-c and were designed to produce different levels of disability glare in the room. Scenario 1 had a wall mounted luminaire with partly unshielded light source and a ceiling lamp. Scenario 2 had luminaires with fabric shade that fully covered the light source. In scenario 3 dimmable spotlights were added to scenario 2 to increase the luminance on the walls.

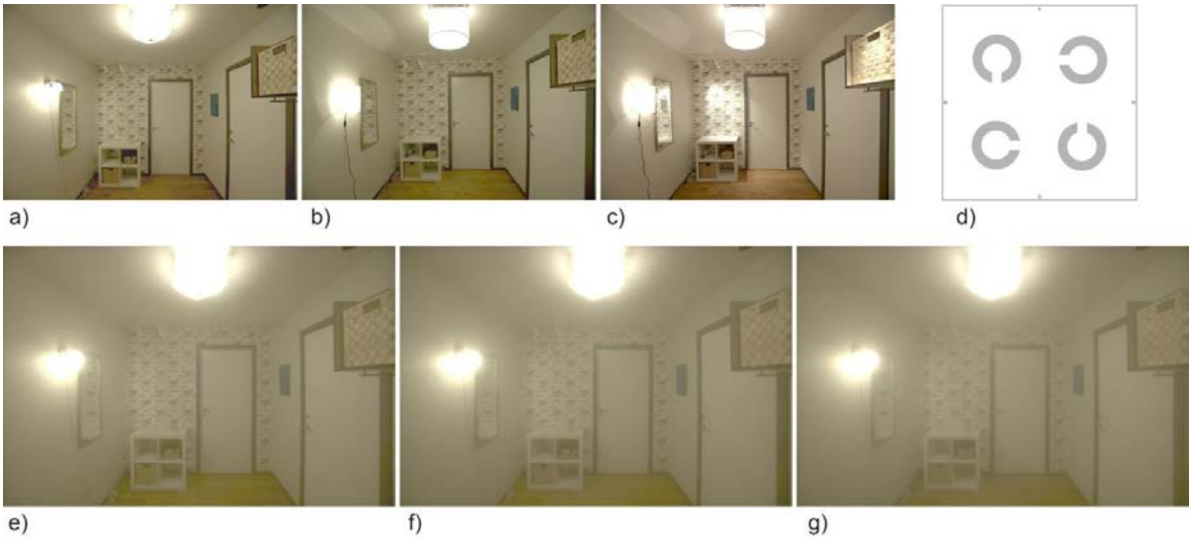

Fig. 1. a-c) The hallway used in the study with light scenario 1-3, respectively. d) Contrast test chart. e-g) Light scenario 1 with simulated veiling luminance of different strength; light, moderate and strong, respectively.

Visual acuity, contrast sensitivity and colour deficiency tests were performed on the observers prior to the assessment in the experimental room where the following assessment techniques were used: 1) *Visual evaluation of light* described in [13]: The observers were asked to describe various aspects of the light, such as light distribution in the room, light level, shadows, perceived colour of light, dimness and clarity. In addition they were asked if they perceived disability glare. 2) *Contrast sensitivity test:* Contrast charts with 'Landolt-C' optotype, see Fig 1d, were used as test symbols and were placed on the back wall, above the shelf, see Fig 1a, where disability glare was assumed to appear. 3) *Preference of light levels and performance at different light levels.* In scenario 3 the observers were asked to do the contrast test at different light levels. 4) *Comparisons between simulation and reality.* The observers compared the visual impression of the real room and the veiling luminance visualization on an iPad 3.

3.1 Conclusions from the study

After analysing the observers' assessments and performances we concluded that scenario 3 was the preferred light setting for these observers, as the luminaries produced the least glare and the spotlights created an adjustable illumination on the contrast charts. In this setting, the participants with cataract made great improvements compared to scenario 1. The simulations predicted the problem areas in the room to a large extent for this group. The result of the analysis of the veiling luminance simulations in the different scenarios showed that the design of the wall mounted luminaire was critical to avoid disability glare as it influenced the visibility of the contrast chart to a large degree.

Comparisons between the visual impression of the real room and the visualizations showed that the observers with cataract on both eyes were not able to compare the real settings with the visualizations. Only the observer who had one normal-sighted eye and one cataract eye was able to judge which strength of the veiling luminance that was the best match. The visualizations agreed with the observation that the colour saturation decreased with increased veiling luminance. However, the visualizations in this study generally lacked contrast and saturation but these parameters have been adjusted accordingly.

4. CAD model simulations

In this study we wanted to verify the correctness of the veiling luminance calculated from a computer generated scene where the light was rendered in a CAD model. The actual scene was also built in reality so intensity calibrated HDR photos were taken in the real environment and the veiling luminance from these HDR images were compared with the veiling luminance calculations based on the light intensity distribution from the CAD model.

The scene was a walkway with streetlights on poles. The development of the CAD model started with a 3D vector model of the ground topography taken from a geographic information system (GIS) database. This model was then processed in Sketchup Pro where material properties were added to the surfaces. This model was then transferred to Relux Pro where luminaires and other objects were added. The light rendering in Relux Pro uses both "raytracing" and "radiosity" techniques, which ensures that both reflected light from surfaces and direct light towards the observer are taken into account. The result is shown in Fig. 2a.

Fig. 2a) CAD model with light rendering of a pathway section. b) Real photo from the same location as in a. c-d) Visualization of contrast reduction due to veiling luminance of the scenes a and b.

The luminance on the ground in the CAD model and on the same position in the HDR images showed good agreement, see Fig 2a and b. The Michelson luminance contrast between the ground and the white solid road line was measured under four of the luminaires along the walkway. The contrast levels varied around 60% and the difference between measurements at the same location in the HDR photo and the CAD model was 2-5%-units.

The veiling luminance was calculated using a simplified eye model [9] and an example of the resulting view is shown in Fig 2c-d. The luminance contrast between ground and road line was calculated at the same locations as described above, after that the veiling luminance contribution had been added to the scenes. Contrast levels were now about 40% in both HDR images and CAD model but the HDR images showed in all locations 5-10%-units higher contrast. The most plausible reason is that the real scenes were illuminated from the sky and spill light from the surroundings that were not taken into account in the CAD model.

The result shows that it is possible to get a good idea about the risk of glare in an environment by analysing a quite simple CAD model with lighting rendering. The scenes from the CAD-model were far from photo realistic, but still included the important light sources that constituted the main contribution to the veiling luminance.

5. Outdoor lighting design

In an outdoor lighting design study of a walkway outside an apartment building, we analysed the veiling luminance contribution in some scenes with simulations based on the eye model described in [10]. We found that the visibility was reduced to such an extent that some people might have problems to navigate. The lighting quality was improved by changing to luminaires that emitted less spill light and illuminated the ground more efficiently. These changes reduced the risk for disability glare which was proven by contrast measurements and glare simulations.

Fig 3a. Original lighting setting. b) Visualization of veiling luminance added to scene 3a. c) New lighting setting with less spill light and reduced risk for disability glare. d) Visualization of veiling luminance added to scene 3c.

The old lighting of the pathway basically constituted of two omnidirectional luminaires located at the corner of the house and on a pole to the right of the pathway, c.f. Fig 3a. These luminaires were the main cause of veiling luminance in an observer’s field of view. The old luminaires were replaced with four luminaires that virtually only illuminated the ground or walls, c.f. Fig 3c. The veiling luminance was calculated according to [10] and based on luminance levels measured from calibrated HDR images captures from the pathway at representative positions and directions. Fig 3b and Fig 3d shows a visualization of the scenes in Fig 3a and Fig 3c respectively, with the calculated veiling luminance added to the scenes. Table 1 summarizes the measured and calculated luminance levels and Michelson contrast levels between pathway and surrounding grass. In the new lighting setting, see Fig 3c, the luminance on the ground was nearly doubled. The veiling luminance contributions to the pathway are almost the same for both settings, but the luminance *contrast* between pathway and surrounding grass with a superimposed veiling luminance is 30% in the new setting instead of only 10% in the old setting, because of the higher illumination of the ground. The overall energy consumption was also halved when less light was emitted in undesired directions.

Table 1. Luminance levels on pathway and contrast between pathway and surrounding grass, for old and new lighting setting.

	Old lighting setting			New lighting setting		
	no veil	with veil	veiling luminance	no veil	with veil	veiling luminance
Luminance on pathway	0.55 cd/m^2	0.68 cd/m^2	0.18 cd/m^2	1.0 cd/m^2	0.83 cd/m^2	0.17 cd/m^2
Luminance contrast	30%	10%		60%	30%	

By analysing the veiling luminance contributions in the scenes we conclude that spill light was the main cause for disability glare in the scene, which was corrected in the redesign. Omnidirectional luminaires reduced the contrasts in the scene to such an extent that navigation could be difficult, and by changing the luminaires we improved the quality of vision which was verified by simulations and luminance measurements.

6. Concluding discussion

The human vision has great capacity to adapt to a large dynamic range of light intensity levels in a scene, but because of optical imperfections, the human eye is unable to form a perfect, high contrast image of a scene if it includes both bright and dark areas. Bright areas tend to smear out as a veiling luminance and mask dark areas in the image. Therefore, the full dynamic range of a scene has to be analysed when trying to predict potential disability glare effects. Not until then, we can foresee visual impressions when the scene is viewed through a human eye.

In our studies, we analyse HDR images of scenes and calculate the superimposed veiling luminance contribution using a mathematical eye model recommended by CIE. We find this model simple to implement in digital image processing. The registration of HDR images can be done by capturing a sequence of images using a standard SLR camera, providing that crucial objects in the scene are not moving. We have successfully analysed the visibility of objects in a scene by inspecting contrast reduction caused by the veiling luminance contribution. This technique points out visual problems and is particularly useful when different lighting settings of the same scene are compared. Our visualization of scenes with superimposed veiling luminance, gives a good indication of the visual problems that might occur, but the images are not exactly what people perceive when observing the scene in reality. Further development is needed to improve the visualizations so that colour appearance and contrasts are better shown.

However, visualizations with the proposed method can still improve the understanding of human vision so that visual aspects can be taken into account in design and quality assurance. Even if an experienced lighting designer often can propose solutions that are both functional and comfortable with high quality of vision even for people with impaired vision, the proposed method can be used to find physical evidence that a design is of high quality and glare free. An existing problematic environment can be analysed before rebuild and improvements can be documented. Standard architectural visualizations usually give nice looking images for communicating the ideas of the design for property owners, developers and other stakeholders, but with our method it is possible to visualize how people are likely to perceive the proposed environment with glare effects of the illumination also taken into account.

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