Straylight in anterior segment disorders of the eye

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Chapter 1
GENERAL INTRODUCTION
INTRODUCTION

Not surprisingly, patients often present to their ophthalmologist with visual complaints. These visual problems are diverse and may be described as hazy vision, difficulty with reading small print, more trouble with distinguishing traffic signs or blinding by oncoming car headlights. Other patients complain of loss of contrast vision causing them to trip on the stairs or pavement, difficulty with facial recognition, loss of colour vision, haloes around lights, or more problems adjusting when going from light to dark, e.g., on entering a tunnel or a darkened room. Patients expect their ophthalmologist to recognize and understand their problems. They would like to see their complaints quantified in a number (e.g., your vision is 50%) and wish to understand what is the underlying cause of the loss of visual quality.

Usually ophthalmologists only use visual acuity measurements with a letter chart to quantify and objectify patient complaints. However, visual acuity measurements are not representative for all aspects of quality of vision. Additional vision tests which measure other aspects of visual functioning could have an added value in assessing subjective quality of vision. To this effect, several glare tests have been developed, which measure the reduction in visual acuity or contrast sensitivity due to blinding by a glare source. The design of these various glare tests involved several different definitions of functional impairment or visual function, and several glare sources. This resulted in inadequate measurement methods, poor correlation with clinical symptoms or poor repeatability. Moreover, the tests were not regularly used, leaving a gap in the routine clinical evaluation of visual performance. The aim of the research leading to this thesis was to examine whether straylight measurements are suitable to fill this gap.

INTRAOCULAR STRaylight; Basics AND CAuses

In a perfect eye, light would pass all structures undisturbed to form a perfect image at the retina. (Figure 1.1A) However, in reality the eye media are not optically ideal and the light passing into the eye will always be scattered to some extent, causing straylight. (Figure 1.1B) Light-scattering in the eye causes a veil of light over the retinal image, reducing the contrast of this retinal image and thus leading to reduced quality of vision. (Figure 1.1C) Glare disturbance due to straylight is very common in the population, as it is ordinarily present in all eyes from early childhood. It is often experienced as a normal visual event.

For a young, normal eye about 10% of the incoming light is scattered by the optical parts of the eye (cornea and lens), by diffuse light reflectance by the fundus, as well as by light transmittance through the apparently opaque ocular structures (iris and sclera). (Figure 1.2) In a young, healthy, Caucasian eye, the cornea and lens each contribute for about 1/3 to intraocular light-scattering, while iris, sclera and fundus cause the remaining 1/3 of scattering.
General Introduction

A: In a normal eye light is focused on the retina to form a perfect retinal image. B: Due to media opacities, some of the light is scattered, leading to straylight. Straylight reduces the contrast of the retinal image, as can be seen when the lower part of C is compared to the upper part.

FIGURE 1.2 Causes of intraocular forward scattered light.
VISUAL EFFECTS

Already in the first half of the 20th century, it was acknowledged that the optical phenomenon of light-scattering in the eye could lead to complaints of disability glare.\(^1\) Disabelle glare is an effect of intraocular straylight.\(^2\) Straylight may cause visual problems as hazy vision, increased glare hindrance, e.g. blinding by a low sun or oncoming car headlights, loss of contrast and color, halos around bright lights and difficulties with against-the-light face recognition. (Figure 1.3)\(^{3,5,7,9,15,17,19,26,27,34,36,38,39}\) Straylight and visual acuity are poorly correlated,\(^{4,6,13,15,19,31,34,36,38,39}\) and the effect of straylight on visual functioning is different from the effect of decreased visual acuity on vision.\(^{14,15,19}\) Typical straylight complaints occur quite independently from visual acuity-associated complaints.\(^{36}\)

FIGURE 1.3 On the left side are shown images as seen by the average normal eye. On the right side, these images are shown as seen by an eye with 2x increased straylight.

Visual quality and the different role of visual acuity and straylight can be better understood by looking at the point spread function (PSF).\(^{21,25}\) Even in an eye with the best possible refractive correction, the image which is projected on the retina remains imperfect.\(^{23}\) When a point light source is projected on the retina, not all light is focused in the same place and the retinal image
is not an ideal point. Some light will be spread over the retina, causing loss of image quality.\textsuperscript{19,21,29}

The PSF is defined as the retinal light distribution of a point source of light and describes the quality of the retinal image, which is the starting point for the visual process.\textsuperscript{19,21,23,26}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{psf.png}
\caption{The point spread function (PSF), divided into several domains, which correspond to different aspects of visual functioning. The central peak corresponds to visual acuity (red), the adjoining parts to contrast sensitivity (blue) and the wide sides to straylight (green). (Figure Graphics: courtesy of Dr Ralph Michael)}
\end{figure}

The PSF consists of two parts: it has a steep central peak and wide sides. (Figure 1.4)\textsuperscript{23} Visual acuity corresponds to the very central peak of the PSF and contrast sensitivity to the adjoining parts between 0.06° and 0.33° of the visual angle.\textsuperscript{13,14,26} Straylight is defined as the outer part of the PSF from 1 to 90°.\textsuperscript{1,13,17,18,21,23,26,33,34} Thus, straylight is concerned with light-scatter over large angles (1° to 90°), while visual acuity is determined by light deflections over small angles (<0.1°).\textsuperscript{15}

The form of the PSF is the result of light-scatter induced by microscopic inhomogeneities and classical wavefront aberrations.\textsuperscript{17} The central peak of the PSF represents the direct imaging of a scene on the retina, which can be measured by visual acuity testing, and the form of this central peak is determined by errors in the refractive media.\textsuperscript{28,34} Irregularities which are very large compared to wavelength cause these wavefront aberrations.\textsuperscript{36} Straylight is caused by light-scatter by small particles and can be measured with psychophysical techniques.\textsuperscript{23} Thus, the two domains of the PSF originate from differently sized processes in the ocular media,\textsuperscript{24} and changes in one domain are not necessarily accompanied by changes in the other domain.\textsuperscript{15} Straylight yields an
effect over the whole range of the PSF and might influence visual acuity and contrast sensitivity.\textsuperscript{40} However, those effects are much smaller than the increase in straylight.\textsuperscript{40} Combined with the steeply declining central peak of the PSF, also little influence on this highest central peak (visual acuity) is to be expected.\textsuperscript{40}

Considering the different effects of straylight and visual acuity on visual performance, straylight measurement could have an additive value in the clinical evaluation of visual functioning.\textsuperscript{1,36}

The clinical and visual effects of intraocular forward scatter can be illustrated in the following case descriptions.

\textbf{CASE DESCRIPTIONS}

The following case histories are added to this thesis to illustrate how debilitating straylight complaints can be. The following patients all presented with (fairly) good visual acuity, but they still felt handicapped due to complaints of decreased quality of vision. When only standard visual acuity measurement was performed, these patients would have felt profoundly misunderstood. Straylight measurements showed the cause of their complaints. Moreover, clinical decision making in these cases was influenced by the amount of straylight.

The first patient is a 62-year old bus driver. He is known with bilateral Fuchs’ endothelial dystrophy and cataract. He complains of increased glare hindrance when driving at night, especially when the oncoming cars have LED headlamps or on wet nights when the wet asphalt reflects the cars’ headlights. During bright days the sunlight blinds him, causing him to see his surroundings hazy and without contrast. To prevent stumbling, he continually wears a cap and sunglasses. Visual acuity of his right eye is 20/25 (0.8) and of his left eye 20/20 (1.0).

The second patient is 67 years old and has bilateral congenital posterior polar cataracts. She first presented to the outpatient clinic of the Department of Ophthalmology of the Academic Medical Center in 2010. She complained of glare hindrance when driving due to blinding by the headlights of oncoming cars. She also reported difficulty when trying to read in the dark. This type of cataract increases the risk of complications during cataract extraction. Due to this fact and her fairly good visual acuity of 20/25 (0.8) in the right eye and 20/30 (0.6) in the left eye cataract extraction was postponed. In February 2012, the patient presented with increased complaints of glare hindrance when driving a car in the evening and at night, which had caused her to stop driving in the twilight and dark. Also at other moments, she experienced increased straylight hindrance to such a level, that she requested to undergo cataract extraction. Visual acuity had not changed compared to 2010 and was still 20/25 (0.8) in the right eye and 20/30 (0.6) in the left eye.
The third patient, 64 years old, is pseudophakic and has undergone a posterior lamellar corneal transplant for Fuchs’ endothelial dystrophy. On the central anterior surface of her intraocular lens (IOL) she developed a dense membrane. Although best corrected visual acuity remained 0.7, she felt visually handicapped as she hardly had any vision in bright daylight. During the day, and even more so on sunny days, she could hardly look out of the window, walk on the street or cycle, as the surroundings would all be blurred and hazy.

The straylight values of these patients were much increased. They can be found on pages 18 and 19 in the section ‘Straylight values of our patients’, after an introduction of how straylight can be measured and what values are to be expected in normal and diseased eyes.

MEASUREMENT OF RETINAL STRAYLIGHT

Despite the previously described drawbacks of using only visual acuity measurements to test the extent of visual quality loss, in the past regular use of additional visual function tests was hindered by the lack of repeatable, sensitive, reliable tests. As a new straylight meter (the C-Quant by Oculus Optikgeräte GmbH, Wetzlar-Dutenhofen, Germany) (Figure 1.5) became clinically available in 2005, this solved the existing clinical difficulties with straylight measurements and a new aspect could be added to the clinical evaluation of visual functioning.

FIGURE 1.5 The C-Quant straylight meter. The patient looks through the central eyepiece with one eye, while the other eye is occluded. He sees the picture on the right with a central test field with two half fields. Light from the flickering large surrounding ring will be scattered towards the central test field. The central test field will appear to become illuminated, but this experience will be the result of straylight. A counterphase compensation flicker is presented in one half of the central test field and the subject is asked to decide which half of the central test field flickers more strongly and to press the button on the corresponding side (2-alternative forced-choice procedure). By analyzing the responses, the amount of intraocular straylight can be determined reliably. The operator can follow progression of the test and check the results and the measurement reliability on the computer screen.
Straylight measurement by the C-Quant is based on the psychophysical Compensation Comparison method.\textsuperscript{1,20,25} The subject fixates on a central test field, which is divided in two halves and surrounded by a large annulus-shaped light. (Figure 1.5) When the test starts, the large surrounding ring will start flickering. When the light of this large ring is on, most of it will be focused onto the retina to form the ring-shaped retinal projection (the non-scattered light). A small part of it will be scattered in the eye by the non-perfect eye media and will form a veil of light over the surrounding retina. This scattered light will also form a veil over the central part of the retina, the fovea, which is fixated on the two halves of the central test field. Because the fovea is veiled over, the central test field will appear to become slightly illuminated and to assume a somewhat grey tint. In reality however, the test field itself remains black and the light comes from the surrounding ring. When the light of the ring turns off, both test field and ring will appear black again to the subject; thus while the surrounding ring is flickering, the subject perceives a faint flicker in the central test field. During the test, in one of the halves of the test field (randomly chosen) a compensation flicker is added. The subject is now able to compare the flickering in both halves of the test field. In one half, the subject sees only the straylight flicker due to the scattered light from the ring. In the other half the subject sees the straylight flicker with an added compensation flicker, which flickers in counterphase with the straylight. The exact amount of retinal straylight is determined by varying the counterphase compensating light in the test field.\textsuperscript{19,20} The flicker perception in the test field can be extinguished by adjustment of the compensation light to the amount that compensates the scattered light from the flickering ring.\textsuperscript{19,20} The amount of compensation light needed to silence the straylight flicker directly corresponds to the strength of the retinal straylight.\textsuperscript{24} The subject’s task is to decide for each stimulus which side of the test field flickers more strongly (the two-alternative-forced-choice procedure). A psychometrical response curve is computed from the subject’s responses, from which the straylight parameter and a measure for the quality of the measurement are deduced.\textsuperscript{25}

It has been shown that optical measurements of light-scatter and psychophysical assessments of retinal straylight correspond very closely, as an equalization technique is used.\textsuperscript{24} The retina has to compare an unknown luminance with a known luminance; it is known that human observers can very precisely establish identity between two stimuli. Potential retinal asymmetries will not confound the measurements, as the stimuli are switched randomly between the two half fields.\textsuperscript{24} Straylight measurement with the C-Quant can be considered an objective, yet functional assessment.\textsuperscript{36}

Measurement by the C-Quant results in a functional straylight parameter $s$, which expresses the amount of straylight as experienced by the patient. This parameter presents the relation between the amount of unwanted, scattered light, which causes the veil of light over the retinal image, and
the wanted, focused, non-scattered light, which forms the retinal image. Usually the logarithm of the straylight parameter $s$ is used and the result is denoted as $\log(s)$.

To be clinically routinely useful, an additional visual function test should be scientifically valid, fraud resistant and standardised. Moreover, it is necessary that the test is easy to understand, to explain and to perform.\(^1\) The measurement should also be repeatable and should correlate with patient's symptoms.\(^2-6\) Straylight is easily assessed in clinic with the C-Quant. As the technique is non-touch and lasts only around 1.5 to 2 minutes, it is not cumbersome to the patient. The outcome of the straylight measurement cannot be consciously influenced by the patient, in contrast to visual acuity measurements, making the test very resistant to fraud from the patient.\(^1\) For the operator, it is virtually impossible to influence the patient's outcome.\(^39\) There is no learning effect when the test is performed repeatedly.\(^20,41-43\) The instrument supplies a reliability index, called the “estimated standard deviation” (ESD), for each measurement.\(^25\) Measurements should only be included when ESD is considered reliable (below 0.1).\(^25\) The C-Quant gives highly reproducible results for untrained subjects over a large range of straylight values.\(^20,32\) A reference data base was established in a large European multicenter study, in which straylight values of more than 2400 subjects were included.\(^34\)

**NORMAL AND ABNORMAL STRAYLIGHT VALUES**

The amount of intraocular straylight between healthy, contra lateral eyes of the same person is usually nearly identical,\(^43\) but between individuals with healthy, normal eyes quite significant variations can exist.\(^10,12,38-44\) Population-based studies have shown that very different straylight levels can be found in the normal population and that considerable straylight increase is frequently encountered.\(^1,14,15,20,44\) Factors as age and pigmentation influence the amount of intraocular straylight.\(^1,13,19-21,23,29-30,46\) Iris colour is shown to influence the intraocular straylight level, with a light-blue-colored iris being associated with significantly higher straylight levels than green-hazel or brown eyes.\(^1,13,17,38-42\) In eyes with little pigment, an increased amount of intraocular straylight is due to the higher iris translucency, to the higher fundus reflectance because of lower fundus pigmentation and to the higher transparency of the less pigmented ocular wall.\(^1,13,17,20,29,31,42\)

In the aging eye, the amount of straylight increases, mostly due to age-related changes in the crystalline lens.\(^1,4,13,15,17,22,23,26,32,34-36,44,46\) Higher straylight values indicate more glare sensitivity and a more compromised visual function.\(^31,34\) Straylight in healthy eyes starts to increase slowly from about forty years of age, doubles around 65 years and triples by the age of 77 years.\(^1,7,14,15,17,21,31,44,45,47\) In eyes with ocular pathology, much higher straylight values may be found.\(^1,14,15,17,29,30,34\)
our case descriptions. Extremely high straylight values lead to much loss of visual quality, even if visual acuity remains reasonable, and these high straylight values cannot be ignored in clinical decision making.

**STRAYLIGHT VALUES OF OUR PATIENTS**

The 62-years old bus driver with bilateral Fuchs’ endothelial dystrophy and cataract and visual acuity of 20/25 (0.8; right eye) and 20/20 (1.0; left eye) had straylight values of \( \log(s) = 1.58 \) (right eye) and \( \log(s) = 1.55 \) (left eye), corresponding to elevations of respectively 4.8x and 4.5x compared to the young normal eye. These values are elevated compared to normal straylight values for age-related, healthy eyes. The nature of his complaints was explained to the patient. It was also explained that, despite his good visual acuity, quality of vision was worse due to the Fuchs’ dystrophy and cataract. Therapeutic options (cataract extraction, possibly followed by a lamellar corneal transplant) were discussed, as was the chance of postoperative improvement.
in quality of vision. Straylight values are expected to improve postoperatively (chapter 5 of this thesis). The patient decided his complaints were tolerable at the moment and he preferred to postpone surgery. At a next control visit it is possible to document whether progression of the disease has taken place, by repeating straylight and visual acuity measurements.

The 67-years old patient with bilateral congenital posterior polar cataracts and visual acuity of 20/25 (0.8) in the right eye and 20/30 (0.6) in the left eye had a straylight value of log($s$) = 2.09 in the right eye, which is 7.5x elevated compared to straylight in age-related, normal eyes. The straylight value in her left eye could not be determined exactly, but was clearly also extremely elevated. The patient decided to undergo cataract extraction, which was performed successfully in her left eye first. Postoperatively, the patient was very satisfied with her visual quality. Visual acuity in her left eye had improved to 20/20 (1.0) and straylight to 1.20, which is a normal value for healthy eyes of this age. Currently, the patient is on the waiting list for cataract extraction of her right eye.

The third patient with the membrane on the central anterior surface of her intraocular lens (IOL) and best corrected visual acuity of 0.7 had a straylight value of 2.08log($s$), which is 8x elevated compared to normal values of healthy eyes of the same age. The dense membrane occupied the major part of the area of the natural pupil. As the pupil widens and the pupil area increases, the percentage which is occupied by the membrane consequently decreases and the part of incoming light which is scattered by the membrane decreases as well. A larger part of the incoming light can be focused on the retina. Thus, the patient started the use of pupil dilating eyedrops. Although best corrected visual acuity decreased from 0.7 to 0.4, the patient was satisfied with the use of these eye drops as she considered visual quality to have improved. Straylight had decreased by 1/3 to log($s$) = 1.98.
References

Chapter 1


