Compensation Comparison

in the Oculus C-Quant Straylight Meter

Contents

Introduction

We know that disturbances to the eye media may cause vision loss of small detail. This can be determined with visual acuity assessment using a letter chart. But eye media disturbance can do much more harm, because it may cause light scattering, resulting in a veil of straylight over the retinal image (see Figure 1). The patient complaints may include hazy vision, increased glare hindrance, loss of contrast and color, etc. These problems are much enhanced if visual function is already low from retinal pathology, such as in macular degeneration or glaucoma.

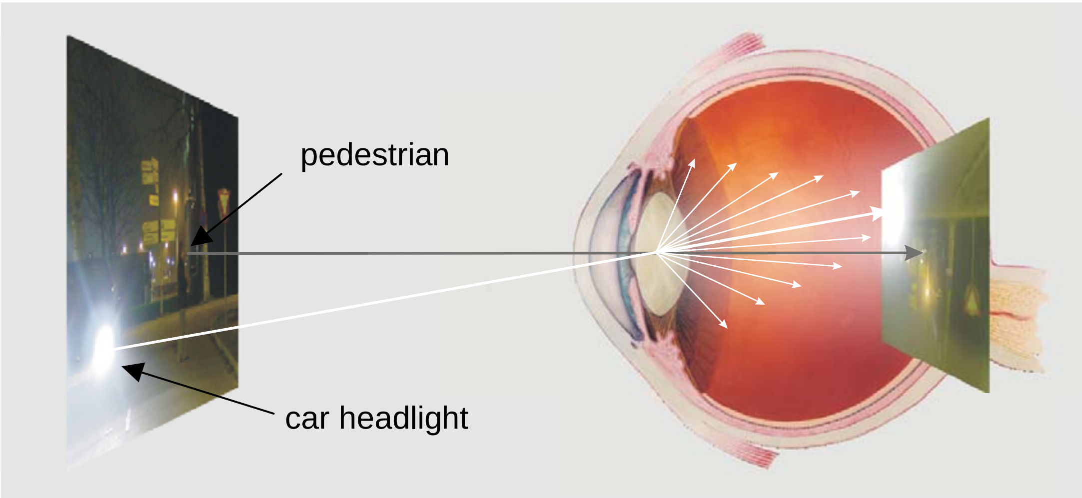

Figure 1: Visualization of retinal straylight. The optical components of the eye form an image of the outside world (left picture) on the retina (right picture). In the case of such a street scene, the picture on the retina is much degraded. Street objects are much less visible compared to the original picture. This is caused by the fact that part of the light coming from the car headlight is scattered in all forward directions (represented by the white arrows in the figure), projecting a veil of light over the retinal image which causes a decrease in the contrast of this image. This veil of light is called straylight.

Straylight in the eye is caused by optical imperfections in the eye media, such as the cornea and the crystalline lens. The amount of straylight is different for each individual, and may even be different for the two eyes of one individual. It depends on age, pigmentation, pathologies such as cataract, and may change due to human interventions such as refractive surgery.

The C-Quant Straylight Meter determines, in an accurate and objective way, the amount of straylight in a patient's eye. This is illustrated in Figure 2, where the Straylight Meter outcome is translated to a real-life situation.

Figure 2: Night scene as seen by an individual with normal (left) and increased straylight (right). With the test outcome of the Straylight Meter we can determine the intensity of the veil of light obscuring the scene, as the patient sees it, e.g. at the location of the pedestrian (red circle both figures). This veil of light is straylight originating from the car headlight.

The C-Quant Straylight Meter uses a psychophysical technique called Compensation Comparison. This document is intended to give some background information about this technique, for those who are new in this field.

The first principle to be explained is the Direct Compensation technique that was used in the original version of the Straylight Meter. In this section, the need for the flickering ring is explained, as well as the difference between scattered and non-scattered light, and the concept of compensation light.

Then the step to Compensation Comparison is made, the technique that is used in the C-Quant Straylight Meter. The properties of the subsequent stimuli that are presented to the patient during a measurement are explained, leading to the psychometric function, a well-known concept from psychophysics. The 50% point of the psychometric curve is introduced, which in our case directly gives the straylight value.

In the last section, the implementation of these principles in the C-Quant Straylight Meter, as well as some added features, such as luminance equalization, instruction phase, initial and final phase, and measurement range categories are explained.

1 Previous method: Direct Compensation

Originally, the Straylight Meter was based on a slightly different principle than the present version. The instrument had a simple design and was mainly used to study the basic properties of human retinal straylight. However, it proved to be not suitable for routine large-scale clinical use. In this instrument, the test field in the center was one whole circle, contrary to the current C-Quant version, where the test field is subdivided into two half fields. The layout of the old test screen is illustrated in Figure 3.

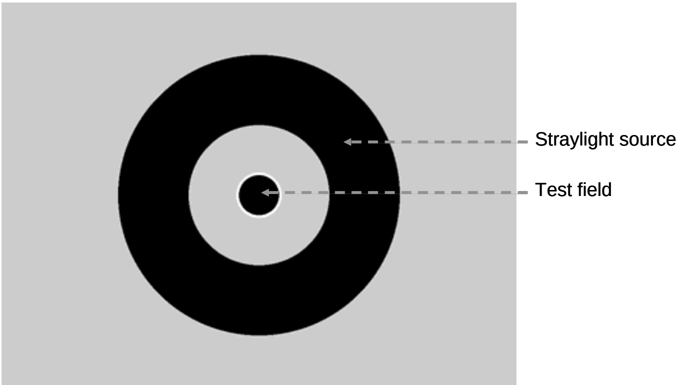

Figure 3: Test screen layout for a Direct Compensation based Straylight Meter

There are two fields in the screen where something happens during the test: the ring-shaped straylight source and the disc-shaped test field in the center. The rest of the screen remains gray throughout the measurement. The subject fixates the test field. If this test field is black, he would normally see it as black. When the test starts, the straylight ring starts to flicker. This means the ring is intermittently white and black. When it is white, we call it the on-phase, and when it is black, we call it the off-phase. What happens with the light from the ring that reaches the subject's eye? Have a look at Figure 4: in the on-phase, the ring is projected on the retina (the non-scattered light), but, due to optical imperfections of the eye media (such as a cataract), a small part of the light that originates from the ring is scattered to other parts of the retina, including the fovea. The fovea is looking at the black test field, and therefore, as the subject sees it, the test field does not appear black anymore, but a little bit gray. In reality, however, it is still black. All the light is coming from the ring (to be precise, there is also some light from the gray areas, but we will disregard this for the moment), and there is no light coming from the test field.

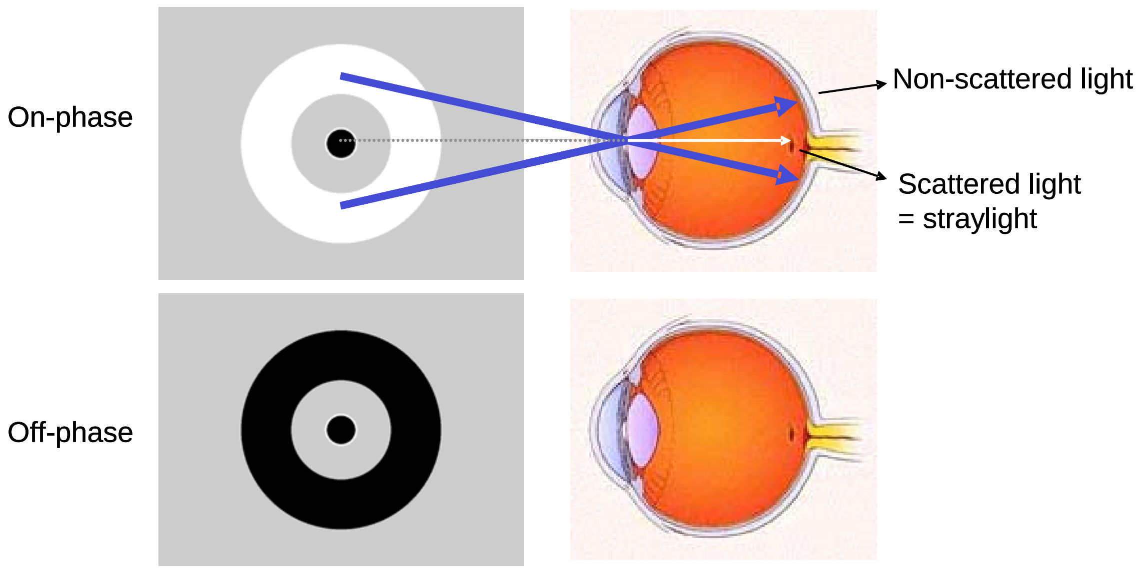

Figure 4: The straylight from the ring in the on-phase is alternated with no straylight in the off-phase, resulting in a flicker perception in the central test field.

In the off-phase there is no light coming from the ring, so the ring, as well as the test field, appears black to the subject. As a result, as the on- and off-phase are alternated, the test field seems to be flickering, i.e. alternating between grey and black, in phase with the flickering ring.

Remember the purpose of the Straylight Meter: we want to quantify the amount of retinal straylight in a subject's eye. This means that we want to quantify the *amount* of light that is flickering on and off in the test field as the subject sees it. For this purpose, we add some light in the test field in the off-phase (see Figure 5). The amount of light is adjustable and we call it compensation light, for reasons that will be explained as follows. Because of this light the test field will become a bit gray in the off-phase. But for the subject it appears gray in *both* the off-phase and the on-phase.

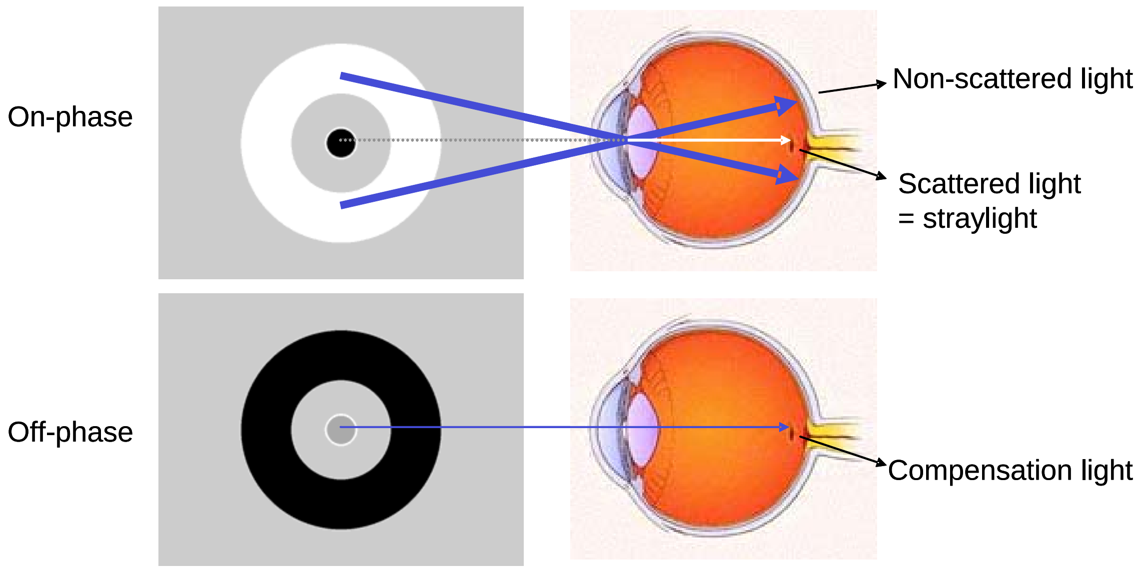

Figure 5: The straylight in the on-phase is compensated by the compensation light in the off-phase. This compensation light can be adjusted to match the straylight, thereby causing the flicker perception in the test field to disappear. This is called Direct Compensation.

One can imagine that, because the test field is now gray in both the on- and off-phase, it will be flickering less than when there was no compensation light. If we make the compensation light in the off-phase the *same* as the straylight in the on-phase, the flicker in the test field will even completely disappear. In other words, the straylight flicker will be *compensated* by the compensation light in this case. Because we know how much compensation light we put in the test field, we also know the amount of straylight in the subject's eye, which was the goal of the whole procedure.

So, if we want to know the straylight value of a subject, all we have to do is let him look at the test screen, make the ring flicker, vary the amount of compensation light in the test field, and ask the subject at which setting he sees no flicker in the test field. This procedure is known as the Direct Compensation method.

2 C-Quant method: Compensation Comparison

The Direct Compensation based Straylight Meter was tested in many subjects. From these measurements, it appeared that, for many of them, the task of deciding when there is no flicker in the test field, while at the same time there is a heavily flickering ring in the surroundings, was very difficult. Also, this instrument did not allow assessment of the quality of the measurement or, in other words, the reliability of the answers of the subject. Moreover, we wanted to improve the measurement accuracy, make it fraud resistant, and make the test easier to administer. Therefore, a new version of the Straylight Meter was developed, that takes the Direct Compensation principle one step further: the Compensation Comparison based Straylight Meter.

Compensation Comparison based Straylight Meter

To facilitate the decision task mentioned above, the Compensation Comparison based Straylight Meter was developed. The stimulus field of this Straylight Meter is very similar to the Direct Compensation version (see Figure 6). The most important difference is that the test field is now divided into two halves.

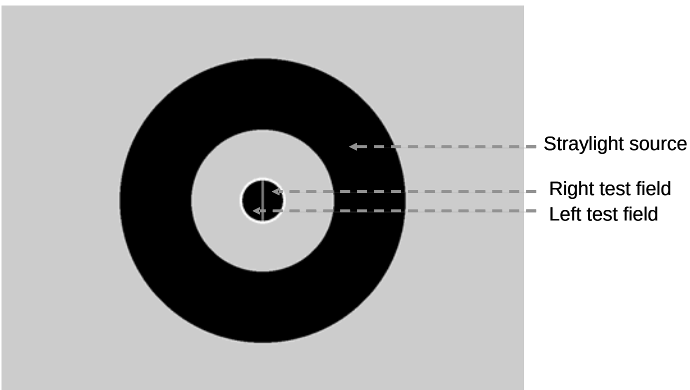

Figure 6: Test screen layout for the Compensation Comparison based Straylight Meter

Another difference is that during a measurement the stimulus is no longer presented continuously, but in a series of short duration stimuli. These stimuli are identical with respect to the flickering ring and the gray surroundings. Only the two test fields differ between the stimuli. One of the test fields is black all the time. In the other test field compensation flicker is added. So, one test field corresponds to the starting point in the Direct Compensation method, and the other test field corresponds to some compensation value in the Direct Compensation method. In this way the subject can *compare* different compensation values to no compensation. The task for the subject is to decide for each stimulus which test field flickers stronger: left or right. During the test the left/right location of the two test fields is randomly varied with each stimulus.

The test field without compensation is black all the time. But, because of the straylight, the subject will perceive a flicker in that test field as soon as the ring starts to flicker. Obviously, the same straylight also causes a flicker perception in the other test field. But in this test field compensation light is presented that is different for each stimulus. In this way the perceived flicker in this test field will be different for each stimulus. Depending on the amount of compensation light, it can be more or less than the flicker in the test field without compensation. If the subject decides the side with compensation is flickering stronger, we denote this as a “1” score, if he chooses the side without compensation, we call it a “0” score.

In the following paragraphs, a somewhat simplified version of the C-Quant Straylight Meter is described. The differences with the actual C-Quant will be described in chapters 3 and 4.

Let us consider the stimuli represented with numbers 1 to 7 in Figure 7 for a subject with known straylight. The amount of straylight corresponding with the ring is supposed to be 10. There is no straylight when the ring is off (value 0). This means, in the test field without compensation the subject sees a modulation between 10 and 0 or, in other words, a flicker with a modulation of 10.The first stimulus has no compensation light in either of the test fields, and therefore both test fields are identical. In the second stimulus, there is a small amount of compensation light in one of the test fields, increasing with each subsequent stimulus until it reaches a certain maximum value in stimulus no. 7. Let us consider what responses we may obtain, for each of these stimuli, to the question which side flickers stronger. To a certain extent, we can predict the responses because the straylight value of the subject is known.

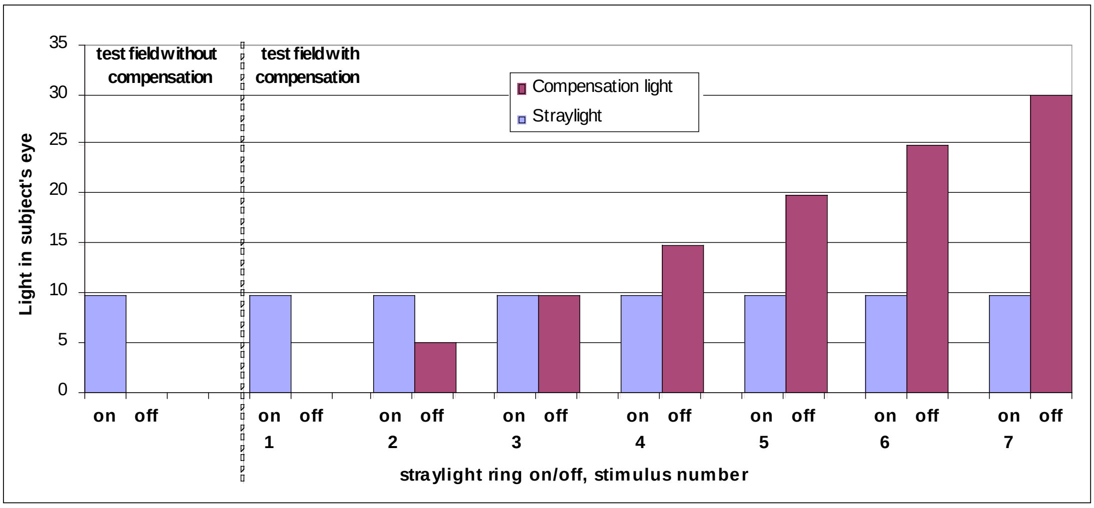

Figure 7: The light that appears in the subject’s eye (in arbitrary light units) in both the on- and off-phase in both test fields. In one test field only the straylight is seen by the subject, staying the same for all stimuli. In the other test field the compensation light is varied with the different stimuli, changing the flicker perception in that test field. The subject has to judge which of the two test fields flickers stronger.

In the first stimulus (no. 1 in Figure 7) the compensation light is zero. Both test fields are identical, and therefore the subject sees no difference between them. However, the subject has to make a choice anyway (this is called a “forced choice” procedure). There is a 50% chance that he will choose the one side, and a 50% chance that he will choose the other side. The score will be either 1 or 0, but if we present this stimulus several times, the average score will be 0.5. Table 1 gives the figures for each stimulus.

Table 1: The modulation in both test fields can be derived from Figure 7. Because there is no compensation light in one test field, the modulation there is always 10-0=10. The modulation in the other test field is the compensation light minus the straylight (which was assumed to be 10). Modulation difference=modulation no comp field minus modulation comp field. The average score is explained in the text.

stimulus number	compensation light	modulation no comp field	modulation comp field	modulation difference	average score
1	0	10	10	0	0.5
2	5	10	5	-5	0.1
3	10	10	0	-10	0
4	15	10	5	-5	0.1
5	20	10	10	0	0.5
6	25	10	15	5	0.85
7	30	10	20	10	1

In the next stimulus (no. 2), the compensation light in one test field is 5, so the modulation the subject sees in this test field reduces to 10-5=5. This is less than the 10 he sees in the other test field, so the score may be 0: the test field without compensation flickers stronger. Only, the difference between two flickers of unequal size is not always judged properly. If we present this stimulus a few times, the subject may sometimes choose the wrong side (score 1), let’s say in 10% of the cases. The average score is then 0.1.

Stimulus no. 3 is special, because here the compensation light is the same as the straylight, so there is no modulation in the test field with the compensation (10-10=0). This is the Direct Compensation situation we were looking for in the previous version of the Straylight Meter. Because there is no flicker at all in the test field with compensation, it is easy for the subject to decide that the test field without compensation flickers stronger: the average score will be 0.

In stimulus no. 4, the compensation light is 15, and the modulation in the corresponding test field becomes 15-10=5, just as in stimulus no. 2. The modulation in the test field without compensation is again stronger (it’s still 10 there), so the subject’s score should be 0. But, just as in stimulus no. 2, the difference in modulation is only 5, which may be a bit hard to see by the subject, and sometimes the score may erroneously be 1. The average score may again be 0.1.

Stimulus no. 5 is a special case also. The compensation light is 20, and the modulation in the corresponding test field becomes 20-10=10. This is the same as the modulation in the other test field (nothing has changed there), so the subject cannot see a difference in modulation between the two test fields, just as in stimulus no.1. Because the subject is asked to give an answer anyway, the score will be either 1 or 0, but after several repetitions of this stimulus the average score will be 0.5.

In stimulus no. 6, the compensation light is 25, and the modulation in the corresponding test field becomes 25-10=15. This is now more than the 10 in the other test field, so the score of the subject should be 1. But, just as in stimulus nos. 2 and 4, the difference in modulation is only 5, which may be hard to recognize by the subject, and sometimes the score will erroneously be 0. Let's assume the average score to be 0.85.

In stimulus no. 7, the compensation light is 30, and the modulation in the corresponding test field becomes 30-10=20. The difference in modulation is 10, which may be easy to recognize by the subject. The subject may score 1 for each presentation of this stimulus, giving an average score of 1.

A further increase of the compensation light will also increase the difference in modulation, making the flicker comparison task even more easy. The average score will remain 1 for all these stimuli.

The above mentioned procedure reveals the psychophysical method that is used in the Straylight Meter, known as the Two Alternative Forced Choice (or 2AFC) procedure. There are two alternatives to choose from (left and right), and the subject has to make a choice every time, even if he sees no difference. Subjects must be told that they sometimes have to guess. In fact, some persuasion is occasionally needed to get people to guess. The 2AFC method is well-known in psychophysics. It allows well-established statistical analysis procedures (see below).

Straylight value determination

Why do we need to bother the subject with all these stimuli, if we only want to know where the Direct Compensation point is? For the subject in the example above, the Direct Compensation point was reached with stimulus no. 3. However, for a subject with a different straylight value this will be different. For example, for a subject with a straylight value of 15, you can immediately see in Figure 7 that his Direct Compensation point is reached with stimulus no. 4. Considering that real straylight values may vary by a *factor* of 10, it is clear that it is necessary to present a wide range of stimuli to cover all possible straylight values. In the C-Quant Straylight Meter a procedure has been implemented that needs only 25 stimuli (of 1 to 2 seconds each) to arrive at an accurate straylight measurement (see chapter 4).

Another reason to measure more points than only the Direct Compensation point is to estimate the *reliability* of the measurement (see next chapter).

3 Psychometric function

If we plot the average scores in Table 1 as a function of the amount of compensation light, we get a so-called *psychometric function*. This is shown in Figure 8. Figure 8a shows the modulation the subject sees in the test fields with and without compensation as a function of the compensation light. As the figure shows, the modulation is constant in the test field without compensation, but it varies in the test field with compensation. Figure 8b shows the psychometric function for the comparison task, resulting from the responses to the presented stimuli. In general, a psychometric function is defined as the *chance* of a certain response (right/left in our case) as function of a stimulus value (the compensation in our case).

The psychometric function is a universally used concept in experiments involving human perception. It is used in hearing, olfaction, pain sensation, and also in vision. The psychometric function is different for each perceptual task and also for each individual. However, the general shape of the psychometric function is usually the same for a specific task.

Added value of the psychometric function

There are three aspects of the psychometric function that can be used to improve the performance of the Straylight Meter with respect to the Direct Compensation based version:

1. The most accurate estimate of the straylight value can be made concentrating on the point where the psychometric function is 0.5 (the so-called *50% point* of the curve).
2. The psychometric function can be used to estimate the *reliability* of the measurement.
3. The psychometric function can be used to *optimize the measurement procedure*, leading to shorter measurement times and increased accuracy of the measurements.

These three aspects will be described in more detail below.

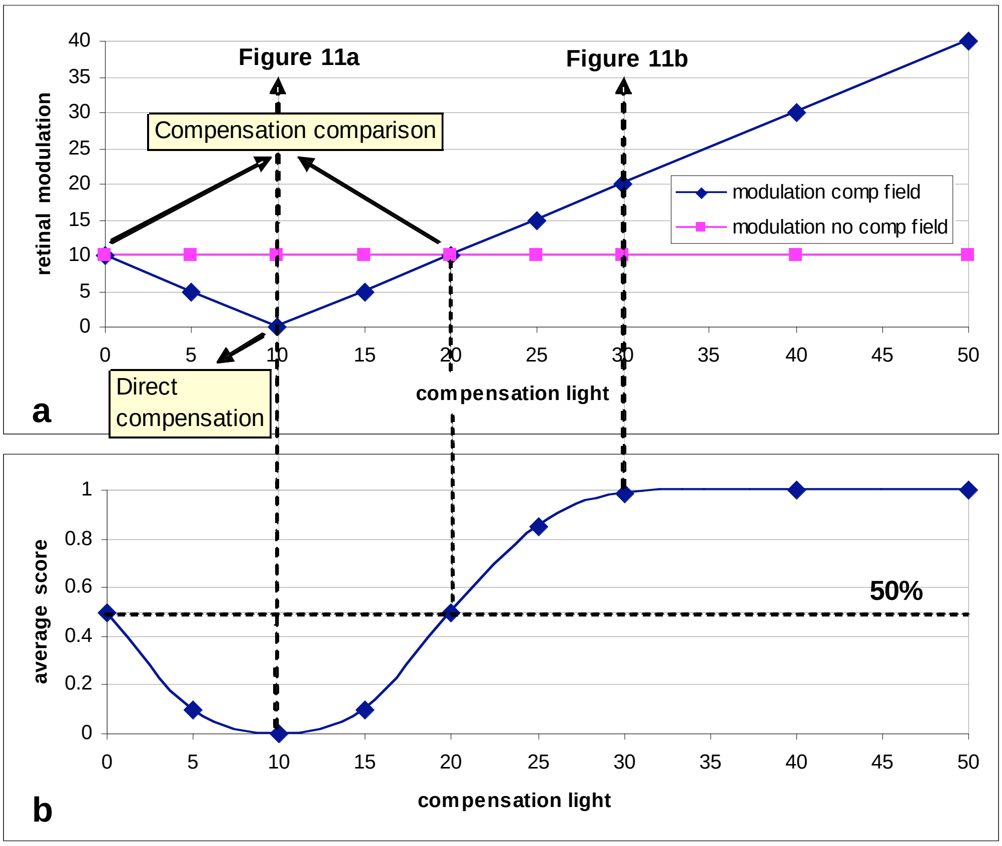

Figure 8: a: Perceived modulation in the test fields with and without compensation as a function of the amount of compensation light in one test field, according to Figure 7 and Table 1. There are two points where the modulation in both test field is equal, resulting in an average score of 0.5. b: Average score as a function of the compensation light. This is the psychometric function for this subject.

50% point
Looking at Figure 8b, we can observe that the Direct Compensation point, where the compensation light is equal to the subject's straylight, and the average score is 0, is not so well-defined. Around this point, the average score is also more or less 0, especially when you have only a limited amount of stimulus presentations. The best-defined point in the curve is where the steepness is at its maximum. This is halfway the transition from 0 to 1, also known as the 50% point (there is also a 50% point on the left end of the graph, but this points contains no information about the straylight value). In this point, the compensation light is two times the straylight value, causing the perceived flickers in both test fields to be equal. Therefore, there is a 50% chance that the subject will judge either test field to be flickering the strongest.

To put it simply, the Straylight Meter "tries" to find the point where, for the respective subject, the amount of flicker is the same in both test fields. This is the 50% point in the subject's psychometric curve for flicker comparison. In this point the compensation light is twice the amount of straylight the subject "sees" because of the flickering ring.

The result of a measurement is a collection of one and zero responses, each belonging to a certain compensation light value. These points can be put in a graph like Figure 8b, and a psychometric function can be fitted to these points to find the 50% point. The fit is done according to the so-called *maximum likelihood* procedure, a method commonly used in psychophysics. It is comparable to the least-squares regression method. Explanation of this procedure is outside the scope of this document.

Measurement reliability
The psychometric function is a means to take limitations in the subject's visual system, such as neuronal noise, into consideration. Because of these limitations, the responses to the presented stimuli will not be exactly the same each time the test is performed, leading to a certain spread in the test outcomes. With knowledge about a subject's psychometric behavior one can estimate the *reliability* of his measurement.

Optimization of the measurement procedure
The shape of the psychometric curve depends on the exact design of the measurement. Examples of design parameters are the size of the test fields and the flicker frequency. Knowledge of the psychometric function (as a function of these design parameters) helps to optimize the test screen layout and the measurement procedure, leading to an increased accuracy of the measurement and/or a reduction in the amount of stimuli needed to attain this accuracy. The Compensation Comparison method offered an opportunity to adjust these design parameters. This provided the possibility to optimize the design of the C-Quant Straylight Meter. This will not be further explained here.

Logarithmic scale
Having explained the importance of the psychometric function in the previous section, we will now have a closer look at the properties of this curve, and see how it changes in a subject with a different straylight value. In Figure 9, the retinal modulation and psychometric curve for subjects with straylight values of 10 (Figure 9a and 9b, identical to Figure 8) and 15 (Figure 9c and 9d) are plotted. For the higher straylight value, the 50% point has shifted to the right (Figure 9b and 9d). This is what you

would expect, because the 50% point is located at twice the straylight value, as explained in the previous section. Obviously, also the Direct Compensation point, which directly represents the straylight value, has shifted accordingly. Moreover, the psychometric curve in Figure 9d is less steep. This can be explained by the so-called Weber law, which is one of the basic laws in psychophysics. This law states that the smallest noticeable difference in a certain quantity is proportional to the average value of that quantity. Around the 50% point of a higher straylight value, the absolute amount of modulation is higher, making it more difficult to judge differences in modulation. In short, a different straylight value changes not only the position of the 50% point, but also the shape of the psychometric curve.

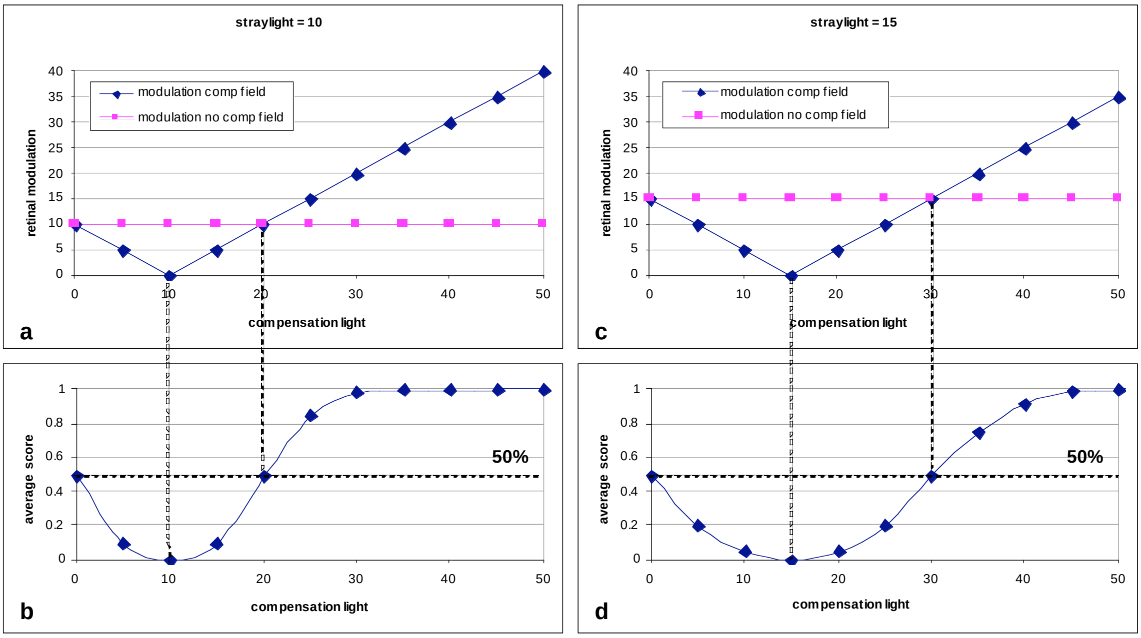

Figure 9: Retinal modulation and psychometric curve for a subject with straylight value 10 (a and b, identical to Figure 8) and a subject with straylight value 15 (c and d). Compared to curve b, the 50% point in curve d has moved to the right (but is still located at twice the straylight value!). Moreover, curve d is less steep than curve b.

Now, consider the psychometric function on a logarithmic scale (
Figure 10b). This causes the shape, including the steepness, to be *independent* of the straylight value. In this plot the only difference lies in the position of the 50% point. This is a direct consequence of Weber's law, and because of this it has become customary in psychophysical studies to plot psychometric functions on a logarithmic scale. Moreover, the importance of psychophysical effects is as a rule better judged on a logarithmic scale. Also the lines on a visual acuity chart are scaled logarithmically. With the Snellen chart this was only approximately true, but the ETDRS chart is exactly logarithmic.

Because of these reasons, the psychometric curve is plotted and also fitted on a logarithmic scale in the C-Quant Straylight Meter. This means that the straylight value, which lies at half the value of the 50% point, is then located 0.3 log units below the 50% point.

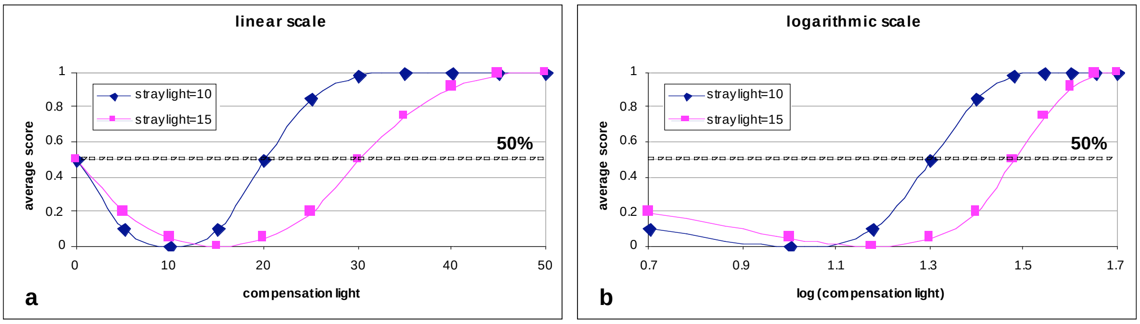

Figure 10: a: Psychometric curves from Figure 9b and 9d combined in one graph (linear scale). Both the position of the 50% point and the steepness of the curve are different. b: Same curves on a logarithmic scale. Now only the 50% point position is different. The whole shape, including the steepness, is now independent of the straylight value. Note that the points in graph a where the compensation light = 0 can not be plotted in graph b, because log(0) = minus infinity.

4 The C-Quant Straylight Meter

In the previous chapters, the principles of the Compensation Comparison straylight measurement were explained in a somewhat simplified way. In this section, the actual implementation in the C-Quant Straylight Meter, as well as some added features, will be described.

Straylight parameter units

In the previous chapters absolute values were used to characterize the amount of straylight and compensation light on the fovea. These values will change when the intensity of the straylight source is different. For example, if the annular straylight source would be made twice as bright, two times as much straylight would fall on the fovea. However, the straylight parameter *s* used in literature, as well as in the C-Quant, characterizes a *physical* property of the eye and is as such independent of the intensity of the straylight source. Accordingly, the straylight parameter is defined in such a way that only the *ratio* between the intensity of the straylight and the intensity of the straylight source plays a role. In the previous chapters this was not an issue because the straylight source was assumed to be constant for all stimuli. However, in reality and also in the C-Quant the straylight source is not always constant (see below). Therefore, compensation and straylight levels are expressed in these *ratio* based straylight parameter units in the C-Quant.

Luminance equalization

The stimuli that were used in the previous chapters not only differ in the modulation they induce on the retina, but also in average luminance. Looking at Figure 7, it appears that the test field with compensation is always brighter than the test field without compensation (except for stimulus no. 1, where both test fields are equal). Such brightness difference could give a clue to the subject about which is the test field with and which is the test field without compensation, giving the opportunity to manipulate the test outcome. Even if the subject is not intending to do this, he might be confused by the luminance difference and judge the stimuli on luminance difference instead of flicker difference. Also, the luminance difference may induce a retinal sensitivity difference. All these effects may compromise the validity of the measurement.

For these reasons, the average luminance in the both test fields is made equal for each stimulus in the C-Quant, by adding an equal offset in both the on- and off-phase of the test field without compensation. This does not influence the (absolute) modulation difference (see Figure 11).

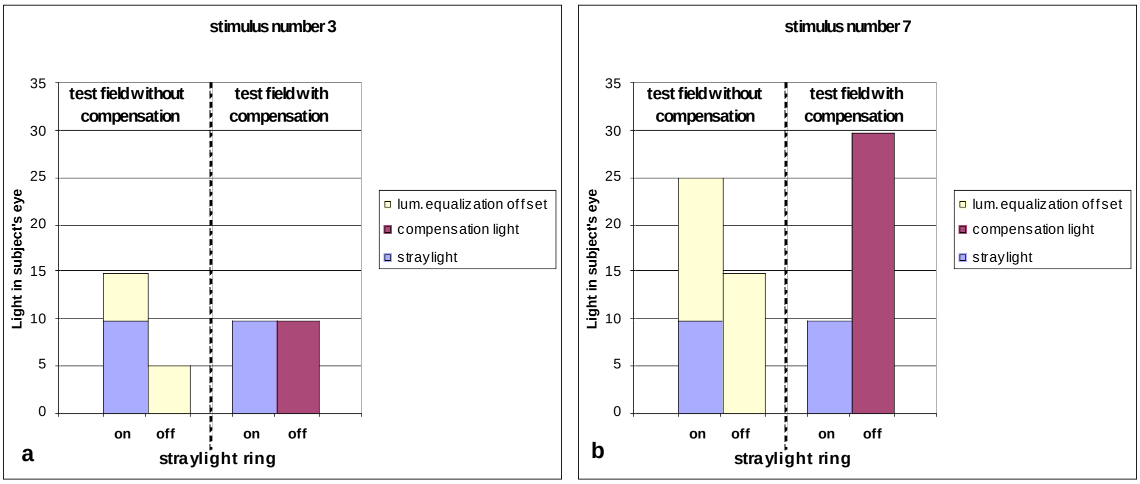

Figure 11: Luminance equalization: to make the average luminance equal in both test fields, an offset is added in the test field without compensation in both the on- and off-phase, retaining the modulation. Because the average luminance in the test field with compensation is different for each stimulus, also the luminance correction has to be different for each stimulus, illustrated by the graphs for stimulus numbers 3 and 7 (from Figure 7).

Instruction phase

In the C-Quant, the first five stimuli are used to familiarize the subject with the flicker comparison task, and to verify if the subject is able to perform this task.

The first three stimuli differ from the remaining stimuli: the ring is not flickering, so there is no straylight flicker in the center. Both test fields are made flickering by putting light in either the on- or off-phase. These stimuli are used to familiarize the subjects with a flicker comparison task, to check if the subject has understood the task and is able to compare flickering signals (in the absence of peripheral flicker). The third of these stimuli can be quite hard to judge for some subjects.

In the 4^{th} and 5^{th} stimulus, the ring is flickering also. These stimuli are in fact the first of the real test, only with such an amount of compensation light that any subject should identify the side with the compensation light with ease, thereby scoring 1. These stimuli are to familiarize the subject with the added complexity of a peripheral flickering ring and to train the subject to concentrate only on the test fields without being distracted by the flickering ring.

If one of the five instruction stimuli is not scored as 1, the C-Quant will give a warning and pause to give the operator the chance to reinstruct the subject before continuing the measurement.

Initial phase and final phase

The measurement with the C-Quant consists of two consecutive stages: the initial or “dark” phase and the final or “light” phase (see Figure 12).

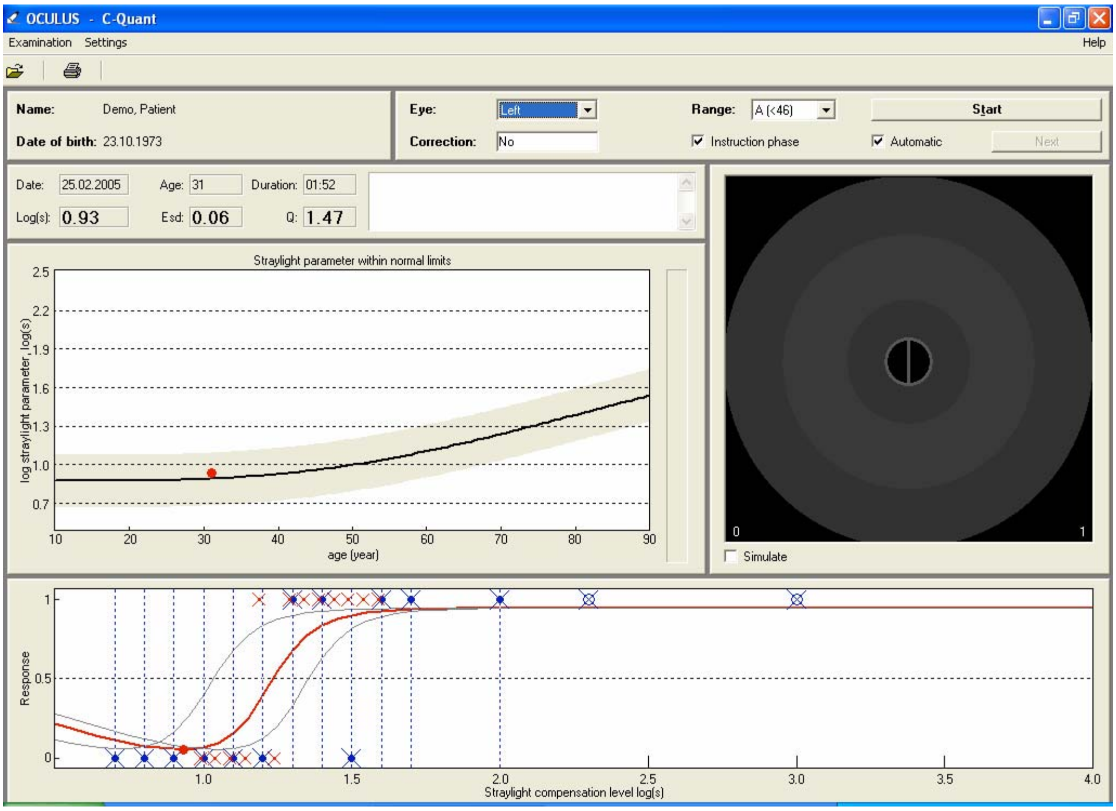

Figure 12: C-Quant operator screen after a measurement. The graph in the lower part gives the subject's responses to the last two of the five instruction stimuli (blue open dots), the initial phase (closed blue dots) and final phase (red dots), as well as the psychometric function fitted to all responses (red curve). The straylight value (0.93 in this case) is marked with a red dot. This value is 0.3 log units below the 50% point of the psychometric curve. The gray curves represent the upper and lower limits of the normal psychometric function range for the age of this particular subject. The test result is also marked with a red dot in the age graph in the left middle part of the screen, showing the normal straylight range for healthy eyes as a function of age. The parameters "Esd" and "Q" are used to estimate the reliability of the measurement.

In the initial phase (the closed blue dots in Figure 12), the variation in modulation in the stimuli is not achieved by variation of the compensation light, as in the previous chapters, but by variation of the intensity of the flickering ring and, as a consequence, of the straylight as well. Each stimulus has a different value on the psychometric curve, in spite of the compensation light being constant for all stimuli, because the value on the x-axis expresses the compensation light *relative* to the intensity of the ring (straylight parameter units, see above). The latter value is different for each stimulus.

The stimuli in the initial phase are equidistant on a logarithmic scale, and presented in a fixed order: from high to low (relative) compensation, or from right to left in the psychometric curve. An advantage of this method is that the ring starts to flicker with low intensity, so that the flicker comparison task is easy in the beginning. The flicker intensity increases with each stimulus until the last stimulus of the initial phase is reached, and the task is becoming more difficult. This relates well to the real-life experience of being hindered more by glare sources with higher intensities, especially at night.

From the results of the initial phase a first estimate of the position of the 50% point is made by fitting a psychometric curve to the measured points. This first estimate was

1.29 in the example of Figure 12. Around this first estimate the stimuli of the final phase are placed. In these stimuli the ring intensity is constant and the compensation light is variable, as in the examples in the previous chapters.

In the final phase, 13 stimuli are presented around the first estimate, but twice as closely packed compared to the initial phase stimuli (red dots in Figure 12). Contrary to the stimuli in the initial phase, they are presented in a random order, according to the psychophysical method of constant stimuli.

At the end of the final phase, a psychometric curve (red curve in Figure 12) is fitted to all data points (initial and final phase results) to find a best estimate for the straylight value (defined as 0.3 log units below the 50% point of the psychometric curve). For the measurement example in Figure 12, the 50% point is found at 1.23, so the straylight value is log(s)=0.93.

Measurement range

One of the design criteria of the C-Quant was to get the best possible measurement accuracy with the fewest possible stimuli presentations. In a clinical environment it is desirable for the test duration to be as short as possible.

For subjects with healthy eyes it is not necessary to test the complete range of possible straylight values. We can make use of the knowledge from population studies about normal variation in straylight values. It is known how, on average, straylight increases with age. Therefore, age categories were introduced that vary the measurement range of the C-Quant. In the C-Quant there are five age categories (see Table 2). In addition, two more categories are provided for cases of increased straylight beyond the normal age-dependent increase, such as with cataract or corneal disturbances.

Table 2: Range settings for the stimuli presented in the initial phase in the C-Quant Straylight Meter

Range	Initial phase compensation levels presented	intended log(s) range	Intended use
A	1.7, 1.6,…0.7	≤ 1.1	Healthy eye (age <=45)
B	1.8, 1.7,…0.8	0.8-1.2	Healthy eye (age 46-55)
C	1.9, 1.8,…0.9	0.9-1.3	Healthy eye (age 56-65)
D	2.0, 1.9,…1.0	1.0-1.4	Healthy eye (age 66-75)
E	2.2, 2.1,…1.2	1.2-1.6	Healthy eye (age>=76)/early opacity
F	2.4, 2.3,…1.4	1.4-1.8	Clear opacity
G	2.7, 2.6,…1.7	≥ 1.7	Severe cataract/corneal edema

The measurement ranges are quite wide, so that the choice of range is not very critical. In fact, most clinical subjects can probably be measured with the default “E” range. This range is intended for a straylight value around log(s)=1.4, as is typical for a very healthy but 80 year old eye. However, 1.4 may occur as pathological in young eyes. If the straylight value of the subject is outside the chosen measurement range, a warning will be given (see below).

C-Quant test result example

An example of the test outcome of a C-Quant measurement was already shown in Figure 12. As mentioned before, the lower graph contains the subject’s responses in the initial and final phase, as well as the fitted psychometric curve, from which the straylight value is calculated. The blue open points on the right are the responses to the 4th and 5th stimulus of the instruction phase (the responses to the first three stimuli are not plotted). The straylight value is marked with a red dot in the minimum of the psychometric curve. The gray curves represent the upper and lower limits of the normal psychometric function range for the age of this particular subject. The normal range is also plotted as a gray band in the age graph in the left middle part of the screen. This graph also includes the red dot that marks the straylight value for this particular subject. In this way it is immediately clear whether or not the subject has an increased value compared to the normal value corresponding with his age. In this example the subject has a normal straylight value.

The upper part of the figure contains the relevant data for the measurement: the subject's name, date of birth, age, measured eye, refraction correction, measurement range, date of the measurement, duration of the measurement, and finally the test outcomes: the straylight value (log(s)) and two parameters for estimation of the measurement reliability: Esd and Q. The exact meaning of the log(s) value is explained in separate documents. It is important to remember that a higher value means more straylight and therefore worse vision, and that an increase in log(s) of 0.3 means a doubling of the amount of straylight, due to the logarithmic character of the value. The Esd and Q values are measures of the quality of the measurement. If Esd is below 0.08 and Q is above 1.0, a reliable measurement has been obtained. This is attainable in most cases. Both conditions have been met in this example, so this measurement can be regarded as reliable. Especially for eyes in worse condition, these strict requirements can be relaxed though.

Additional information

This document is intended as an introduction to the working principles of the Oculus C-Quant Straylight Meter. More thorough references related to this subject can be found in the separate document "C-Quant literature overview". For additional information, please contact:

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