OPHTHALMIC OPTICS FILES

PRACTICAL REFRACTION

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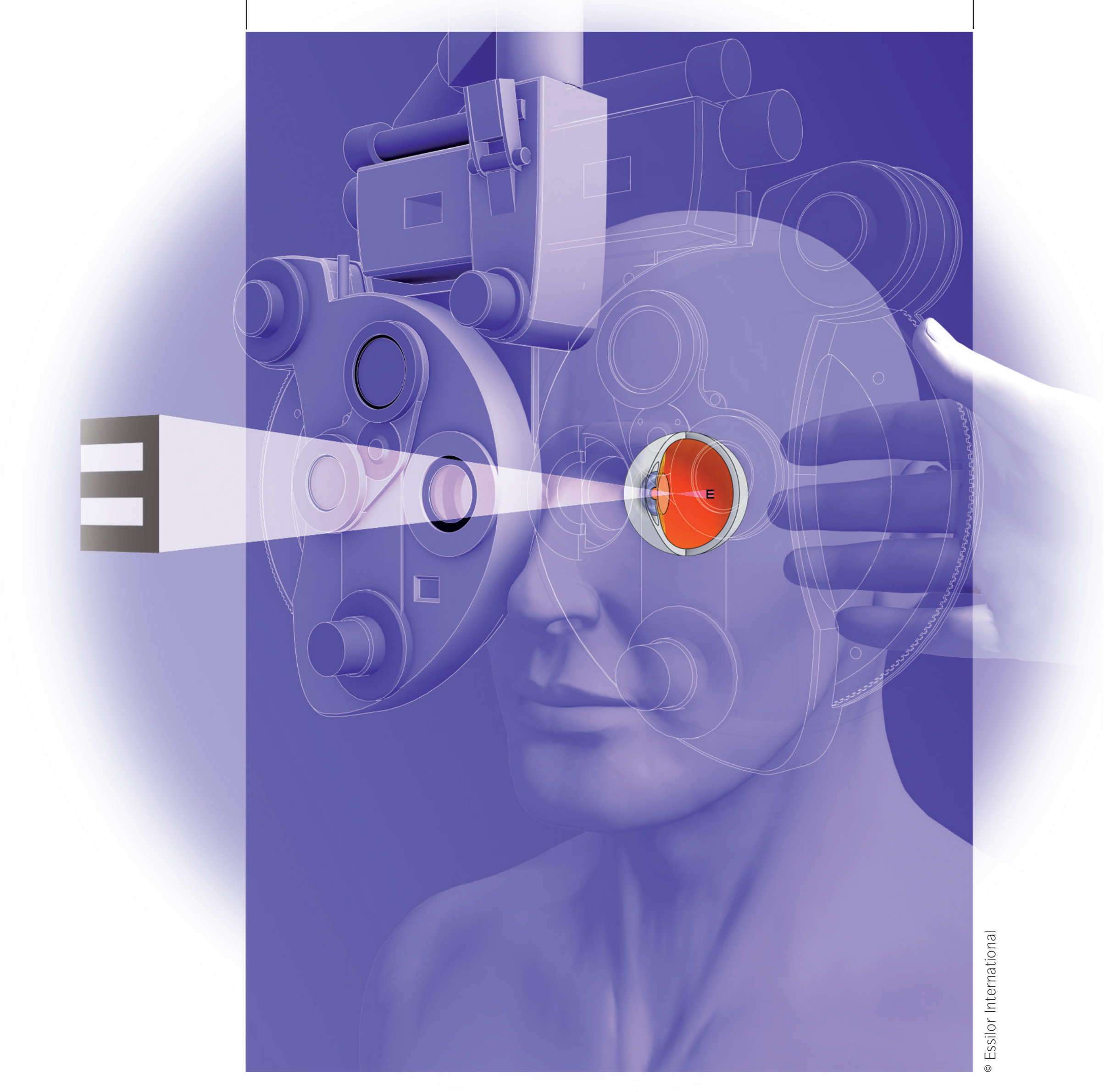

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Practical Refraction

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Summary

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Introduction

The accurate determination of the refraction is an essential prerequisite to ensuring clear and comfortable vision for the patient. Particular attention must always be paid to its assessment.

This document in the Essilor Ophthalmic Optics Files series examines refraction from a practical point of view. The file provides a concise summary of a number of simple and proven techniques selected from the large number of methods available. Its goal is not to deal exhaustively with the subject, but rather to discuss certain basic principles of refraction that are useful to practitioners. The file has been developed in response to numerous requests from practitioners in countries where the practice of refraction is rapidly expanding. The principal objective of this file is to help eye care professionals manage their patients and meet their eye care needs, in the hope that this may increase the level of customer and practitioner satisfaction.

1. Emmetropia, Ametropia, Presbyopia and their correction

When the eye is out of focus, the vision is blurred. There may be several reasons why an eye is not in proper focus, and indeed the reasons why a person develops a refractive error are many and multifactorial, but no matter what the reason, the end result is that there is a mismatch between the power of the refracting elements of the eye and the position of the retina (that is, the length of the eye). The eye has a refractive error and the vision is out of focus when the image formed by the refracting components of the eye is located in front of and/or behind the retina, rather that exactly on it.

A Emmetropia

An eye is said to be emmetropic (from the Greek *emmetros* = proportionate (measurement) and *ops* = eye) when the image of an object located at infinity is formed on the retina of the unaccommodated eye. In the emmetropic eye, the retina is conjugate with optical infinity and therefore lies in the image focal plane of the ophthalmic system. The emmetropic eye sees distant objects clearly, without accommodation.

The eye as an optical system:

The unaccommodated emmetropic eye can be modelled as an optical system composed of the cornea, the aqueous humour, the crystalline lens and the vitreous humour. The characteristics of one such theoretical system (called a *schematic eye*) are shown in the table below:

	Thickness (mm)	Refractive index	Anterior radius of curvature (mm)	Posterior radius of curvature (mm)
Cornea	- (single surface)	-	7.80	-
Aqueous humour	3.60	1.336	-	-
Crystalline lens	3.70	1.422	11.00	-6.48
Vitreous humour	16.79	1.336	-	-

Overall length of eye: 24.09 mm
Reference: Bennett and Rabbetts' *Clinical Visual Optics*, fourth edition, 2007

A *simplified* eye can be obtained (Figure 2) by simplifying this model; that is, by (i) combining the elements that make up the eye, (ii) considering the cornea and the lens as thin lenses (as opposed to thick lenses), (iii) using the same index n = 1.336 for the aqueous and vitreous humours and (iv) rounding off the calculations. This *simplified eye* totals 60 dioptres, is 24 mm in length and is comprised of a transparent sphere with an optical power of 42 dioptres (the cornea) separating the air from the aqueous humour, and a thin lens with an optical power of 22 dioptres (the lens) separating the aqueous humour from the vitreous, located 5.8 mm behind the cornea. Although greatly simplified, this model is nevertheless an acceptable optical representation of the human eye (in the unaccommodated state).

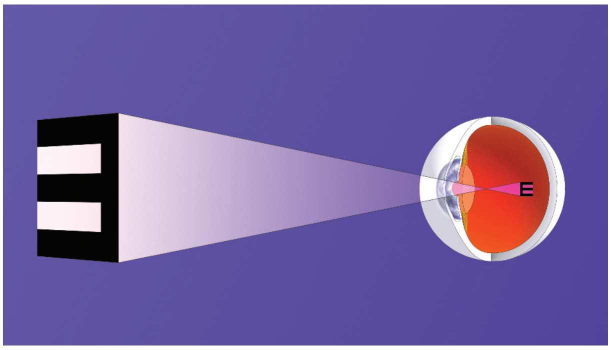

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Figure 1: Emmetropic Eye

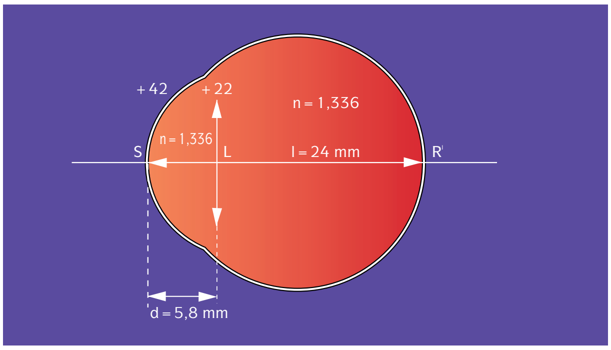

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Figure 2: *Simplified* Emmetropic Eye

B Ametropia

An eye which is not correctly focussed (that is, where the image of a distant object is not formed on the retina of the unaccommodated eye) is said to have a refractive error or an *ametropia* (from the Greek meaning *disproportionate eye*). The different types of ametropia are classified into three categories: myopia, hypermetropia and astigmatism.

1) Myopia (Shortsightedness):

Myopia is the state of refractive error in which the image of an object located at infinity is formed by the eye (in its relaxed state) in front of the retina. The word myopia comes from the Latin *myops* and Greek *muôps* meaning a person who narrows the eyes ("squints" or peers). The person with uncorrected myopia sees distant objects as blurred but can see close objects clearly (they are "sighted" at "short" range).

Optically, the myopic eye presents an excess of power relative to its length. This may be classified either as being because it is too long relative to its power (*axial* myopia (the majority of cases for myopia in excess of 5.00D)), or because the eye is too powerful relative to its length (*refractive* myopia).

Myopia is corrected by the introduction of a minus (negative) powered lens, so as to move the image back and reposition it onto the retina.

2) Hypermetropia (Longsightedness):

Hypermetropia (or hyperopia) is the state of refractive error in which the image of an object located at infinity is formed by the eye (in its relaxed state) behind the retina. The word hypermetropia comes from the Greek *hyper* = beyond (measurement) and *ops* = eye.

Optically, the hypermetropic eye presents a lack of power relative to its length. This may be classified either as being because it is too short relative to its power (*axial* hypermetropia (the majority of cases for hypermetropia in excess of 5.00D)), or because it is insufficiently powerful relative to its length (*refractive* hypermetropia).

Hypermetropia is corrected by the introduction of a plus (positive) powered lens so as to move the image forward and reposition it onto the retina.

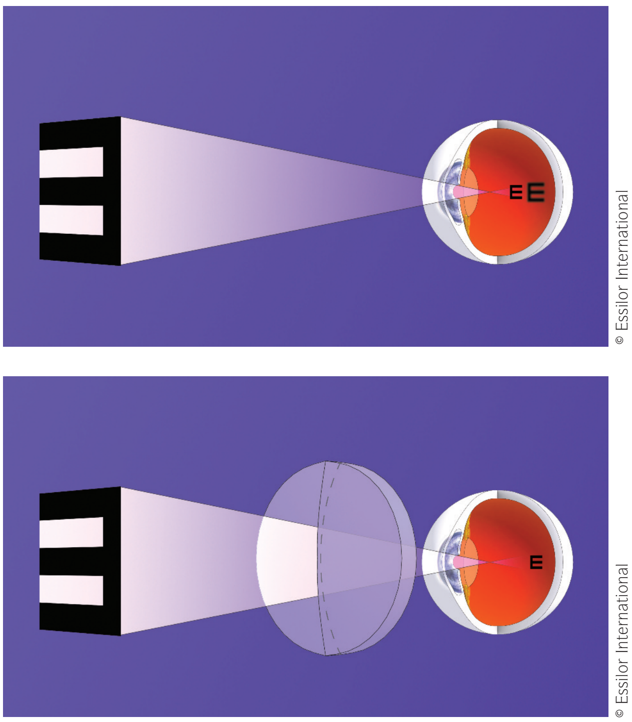


Figure 3: The Myopic Eye and the Principle of its Correction

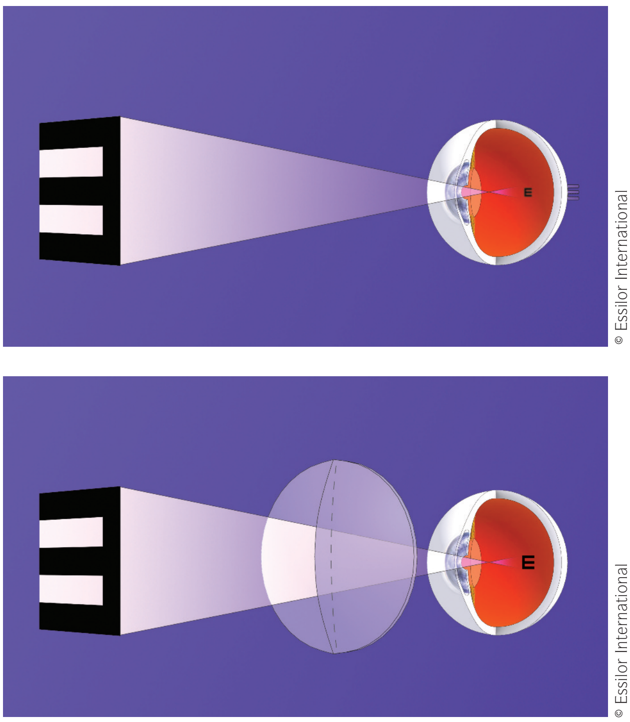


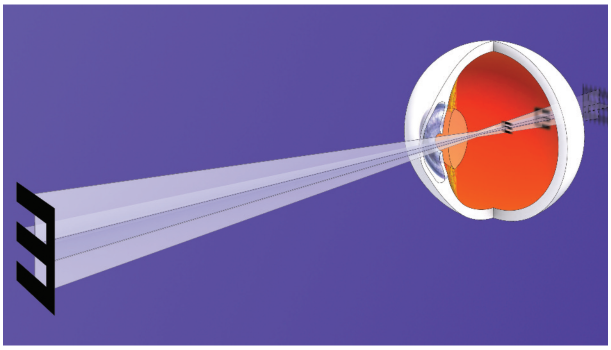
Figure 4: The Hypermetropic Eye and the Principle of its Correction

3) Astigmatism:

An eye is said to be astigmatic when its optical power and therefore its focus differs according to its different meridians. The eye thus presents an asymmetric ametropia with different focal positions in different planes. For example, a person with astigmatism who is looking at a capital letter E may see the vertical line clearly but the horizontal lines as blurred.

In an eye with astigmatism, there is always a meridian of maximum refractive power and another meridian of minimum refractive power; these are termed the *principal meridians*. Between these, the refractive power varies between the maximum and minimum limits.

When the astigmatism is regular, the principal meridians are perpendicular to each other (that is, 90° apart) and the power varies in a regular fashion between these two limits. Astigmatism may also be irregular, where the principal meridians are not perpendicular to each other; this may result from an injury, for example, and is not able to be corrected by spectacle lenses alone.



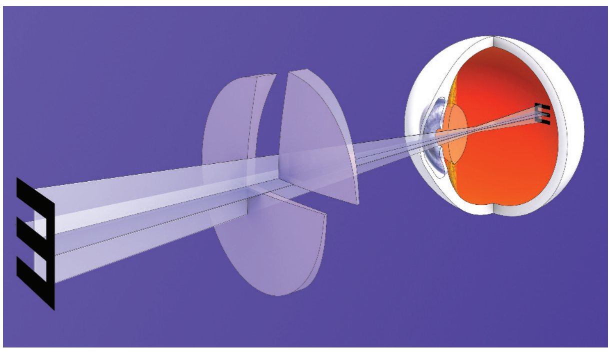


Figure 5: The Astigmatic Eye and The Principle of its Correction

Different types of astigmatism are possible, depending on the location of the two principal foci (that is, the refractive power of the maximum and minimum meridia):

- if emmetropic in one principal meridian and myopic in the other, the astigmatism is termed *simple astigmatism*
- if emmetropic and hypermetropic, it is termed *simple astigmatism*
- if myopic in all meridians, it is termed *compound myopic astigmatism*
- if hypermetropic in all meridians, it is termed *compound hypermetropic astigmatism*
- if hypermetropic in one principal meridian and myopic in the other, it is termed *mixed astigmatism*

The astigmatism is said to be *with the rule* if the most powerful meridian of the eye is close to the vertical (that is, located between 70° and 110°). It is said to be *against the rule* if the most powerful meridian is close to the horizontal (located between 160° and 200°, or +20° and -20°). When the astigmatism is neither *with the rule* nor *against the rule*, it is said to be *oblique*.

The optical system of the astigmatic eye forms a complex light beam image of an object point. This beam is characterised by two small linear foci, each at one extreme of the interval, which are perpendicular to each other. These two foci correspond to the images formed by the principal meridians of the eye. Inside this *Interval of Sturm*, lies a particular location called the *Disc of Least Confusion*. At this location the section of the astigmatic beam is a minimum and at its smallest size. The disc of least confusion is dioptrically equidistant from the two foci, that is, near the midpoint of the interval; it is this location which is positioned on the retina when the *best vision sphere* is in place (see later).

The principle of correction of the astigmatic eye is to introduce a lens of variable power so as to reposition the image onto the retina. The power of this lens varies according to its meridians, inversely to the astigmatism of the eye. The lens is called *sphero-cylindrical*, *cylindrical*, or *toric*. The difference between the refractive power of its maximum and minimum meridians (the cylinder) compensates for the astigmatism of the eye, thereby merging the two linear foci into a single point focus, while its spherical component places this image point on the retina. *With the rule* astigmatism is corrected by a minus cylindrical lens with an axis close to 180° and *against the rule* astigmatism by a minus cylindrical lens with an axis close to 90°. The axis of astigmatism varies throughout life, generally from *with the rule* as a child to *against the rule* as an older adult. Also, the axis of astigmatism in the two eyes is such that it is generally symmetrical around the vertical meridian (the nose).

C Near Vision, Accommodation and Presbyopia

When an object being viewed is brought closer to the eye, the image of this object would be formed further behind the retina unless the power of the eye is increased so as to maintain the image on the retina. The eye has the capacity to increase its overall power and this is achieved by changing the surface curvatures, thickness and position of the lens; this process is the phenomenon of *accommodation*.

The *amplitude of accommodation* is the range over which the eye can focus. It represents the distance between the furthest object point seen clearly without accommodation (the *Far Point*, or *Punctum Remotum*) and the closest object point seen clearly with maximum accommodation (the *Near Point*, or *Punctum Proximum*). In the emmetropic eye, this accommodation range extends from infinity to *the near point* (which is a finite distance). In the myopic eye, the range is real and located entirely at a finite distance in front of the eye. In the hypermetropic eye, the accommodative range is either partly virtual (behind the eye) and partly real (in front of the eye) or wholly virtual.

The value of the amplitude of accommodation determines the nearest point at which an object may be viewed and for which the eye can form a clear image on its retina. The amplitude of accommodation (maximum) is approximately 20 dioptres at birth (corresponding to a *near point* of ~5cm), >10 dioptres (~10cm) by age 20 years, no more than a few dioptres by age 40 years (~35cm), with a total loss of accommodation by the age of approximately 50 years (depending on various factors). This loss of the ability of the eye to accommodate is termed *presbyopia*.

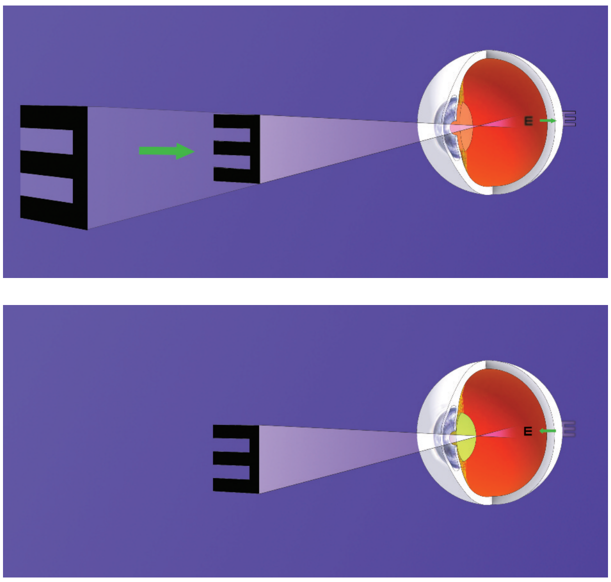


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Figure 6: Near Vision

Presbyopia :

An eye is said to be presbyopic (from the Greek meaning *old eye*) when the shape and position of its lens are no longer able to be altered sufficiently to allow sufficient increase in the refractive power of the eye for a clear image of near objects to be formed on the retina; that is, when the amplitude of accommodation is insufficient for near visual needs. Left uncorrected, presbyopia will cause near objects to be seen as blurry.

The principle of correction of presbyopia is to supplement the insufficiency of the amplitude of accommodation (in near vision) by means of a plus lens. This lens, which is additional to any correction of ametropia, is called a *near addition*, or more simply an *add*. Thus:

- the presbyopic emmetropic eye is corrected by a plano lens for distance and a plus lens for near;
- the presbyopic myopic eye is corrected by a minus lens for distance and a lens which is "less minus" for near (this may mean that the near correction may be minus, plano or even plus, depending on the level of myopia and the add);
- the presbyopic hypermetropic eye is corrected by a plus lens for distance and a stronger plus lens for near

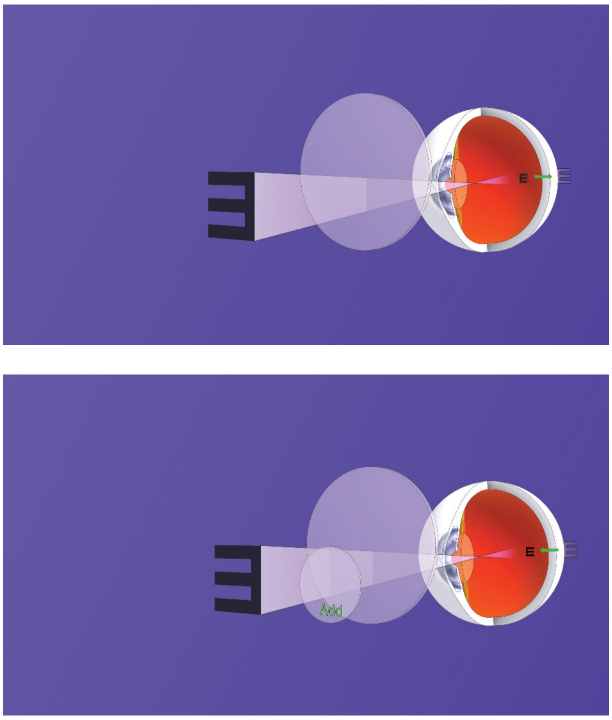

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Figure 7: Ametropia and Presbyopia

The Optical Principles of the Correction of Ametropia and Presbyopia

The Principle of the Correction of Myopia and Hypermetropia

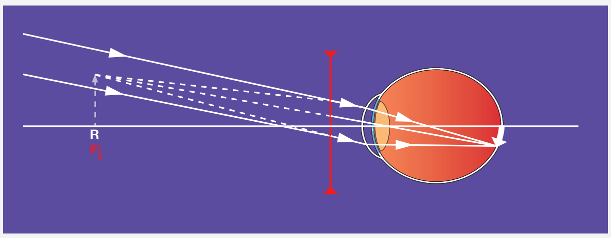
The basic optical principle in the correction of ametropia is the use of a lens to form optical images of objects (seen as blurred by the uncorrected ametropic eye) which the ametropic eye can see clearly. More specifically, correction consists of projecting optical images of objects that are seen as blurred without correction into the space which is seen clearly by the ametropic eye.

In particular, to restore the ametropic eye to the situation of the emmetropic eye, the correction consists in the lens' forming an image of a distant object at the point which the ametropic eye sees clearly without accommodation, that is, at its far point. As the image of a distant object formed by a lens is, by definition, located in its image focal plane, the principle of correction of the ametropic eye is to determine the power of correction so that the *second principal focus of the lens coincides with the far point* of the ametropic eye to be corrected.

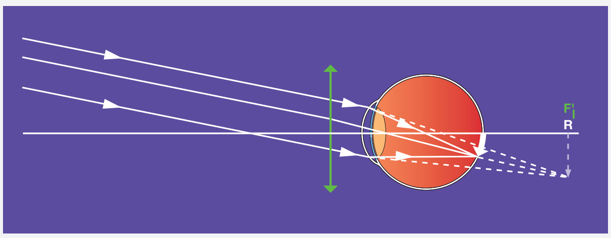
In the case of the myopic eye (Figure 8a), the image of an object at infinity is formed at the (virtual) image focus of the minus lens. That image in turn becomes an object for the eye which, because it lies at the far point, is projected clearly onto the retina since it is conjugate through the optical system of the eye. In the case of the hypermetropic eye (Figure 8b), the image of an object at infinity is formed at the (real) image focus of the plus lens. That image becomes an object for the eye which, because it is located at the far point, is projected clearly onto the retina.

Figure 8: The Principle of Correction of Ametropia

a) the myopic eye



b) the hypermetropic eye



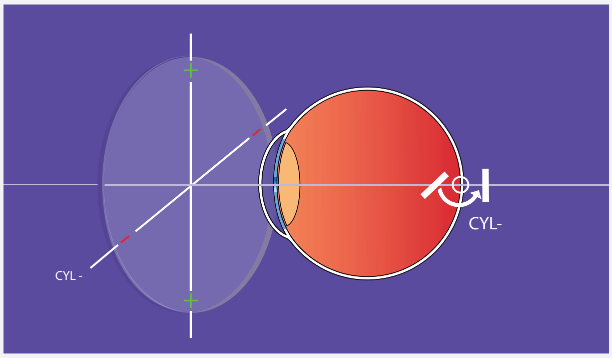
The Principle of the Correction of Astigmatism

The principle of correction of the astigmatic eye is to introduce an astigmatic lens of a power which varies according to the different meridians so as to counteract the astigmatism of the eye. This lens, called sphero-cylindrical, has a difference of optical power between its maximum and minimum power meridians (the cylinder) that compensates for the astigmatism of the eye by merging the two linear foci into an image focal point, and a spherical power that repositions this image point onto the retina.

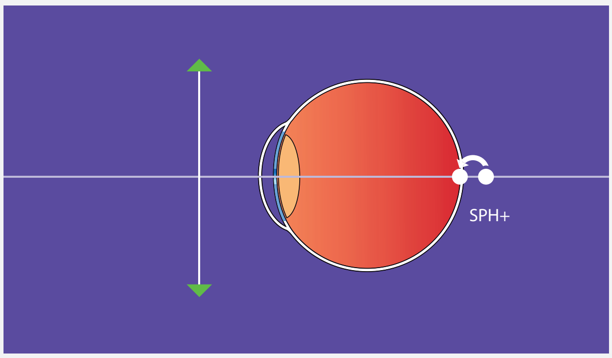
The power of the cylinder acts on the linear focus parallel to its axis. In the case of a prescription for a sphero-cylindrical lens expressed in minus cylinder form, it can be said that the 180° axis cylinder causes the horizontal focus to coincide with the vertical focus, merging them into a single image point, and that the spherical power 'repositions' this image point onto the retina. The *power axis* of a cylindrical lens is perpendicular to its *cylinder axis*.

Figure 9: The Principle of Correction of the Astigmatic Eye

a) the effect of the cylindrical component of the correction



b) the effect of the spherical component of the correction



The Optical Principle of the Correction of Presbyopia

The effect of prescribing a near addition is to restore to the presbyopic eye the ability to see near objects clearly. Its purpose is to produce an image of a near object at a further distance from the eye which lies within the remaining range of accommodation. The apparent range of near vision which results has the optical property of being the object conjugate of the distance vision accommodation range. The image of the *near vision far point* Rp seen through the addition is the *distance vision far point* Rl; the image of the *near vision far point* Pp seen through the addition is the *distance vision near point* Pl. Since Rl is located at infinity (that is, at the *corrected far point* of the ametropic eye or the *real far point* of the emmetropic eye), it follows that Rp always lies in the focal plane of the addition (Figure 10).

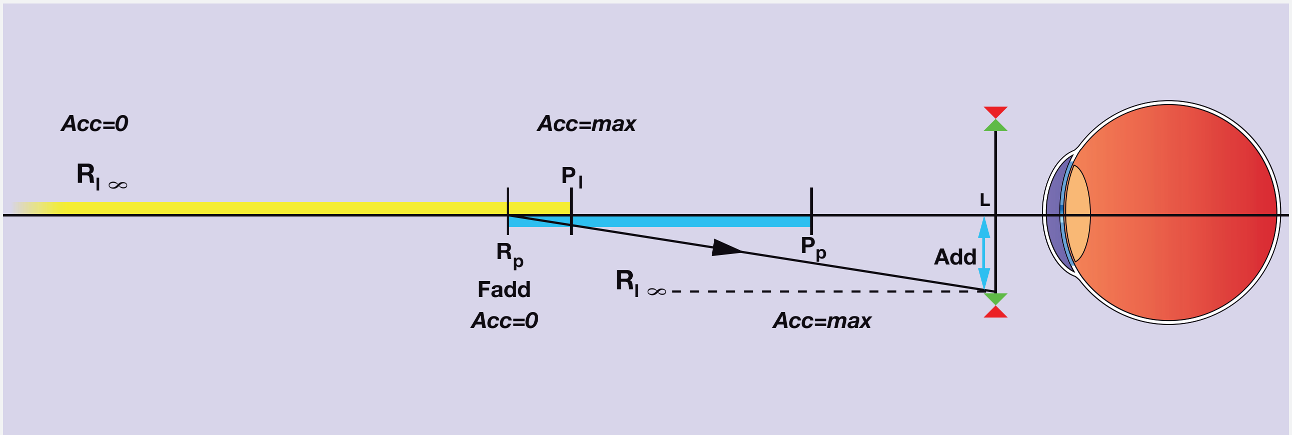


Figure 10: The Principle of Correction of the Presbyopic Eye

Real and Virtual Optical Spaces

Two optical spaces can be distinguished in the ametropic eye corrected by a spectacle lens:

- the *apparent* or *corrected optical space*, which is restored to the ametropic eye by its refractive correction and in which exist the physical objects that it sees. This is the *object space* of the lens.

- the *real optical space*, which is the optical *image space* for the lens and the *object space* for the eye, in which exist the optical images of the objects formed by the corrective lens. These are the images which are seen by the ametropic eye and which are formed on its retina.

Any optical space extends really or virtually to infinity; that is, the *apparent optical space* extends in front of and behind the lens and the *real optical space* extends in front of and behind the eye. The corrective lens acts as a creator of *apparent optical space*. The image of this space is formed, through the lens, in the optical space perceived clearly by the ametropic eye. This is why it is a little improper to speak of *optical correction* by spectacle lenses as the lens does not really correct the ametropia. It would be more appropriate to speak of the *optical compensation* of ametropia by spectacle lenses.

Supplement:

Equipment

To perform refraction, appropriate equipment and facilities are required.

Preferably the location used will be a room specifically dedicated to visual examinations, located in a quiet area away from the other activities of the practice or shop, in order to ensure the patient's privacy and to facilitate concentration. The lighting of the room should be of medium brightness in order to correspond to standard vision conditions. It is important to avoid carrying out visual examinations in dim conditions (unless a particular investigation is required). A distance of 4 to 6 m (depending on the country) will be required, at which a vision chart may be placed to test distance vision. This distance can be obtained directly or by reflection in a mirror. Tests should be presented at the height of the patient's eyes (that is, so the patient looks at distance in primary gaze).

Certain minimum equipment is required:

- Visual Acuity (VA) chart (distance) (including VA charts for children (with confusion bars, and matching prompt cards, etc) and for non-communicating patients (e.g. Illiterate E, Landolt C, matching cards))
- Reading Card or VA chart (near)
- Lens Set (trial frame and trial lens set, manual phoropter or automated phoropter)
- Jackson Cross Cylinder(s) (hand-held or in phoropter)
- an occluder
- appropriate lighting level (for distance vision testing as well as focal lighting for near vision evaluation)
- equipment relating to an objective method of refractive measurement (retinoscope or auto-refractor)
- a vertometer/lensometer/focimeter (its name varies depending on the country), for measuring the current spectacles

Beyond this fundamental equipment, further enhancements may be added, including: tape measure (for measuring reading distance, test distance, near point of accommodation, etc), flippers (for example +/- 0.25D, 0.50D, 1.00D, 2.00D and base in/out prism), pen torch, red filter, polarizing lenses, prism bars, stereoscopy test, cycloplegic topical preparations for use with retinoscopy, where available and appropriate and a contrast sensitivity test.

Figure 11: Refraction Equipment – Manual Phoropter

It goes without saying that the use of these different instruments is restricted to eye care professionals with the required level of qualification and skill, in accordance with the regulations in force in each country.

2. Preliminary Examination

A Case History

To commence any visual examination, it is necessary to review the case history of the patient. This should be done in order to understand the symptoms that have motivated the patient to seek a consultation as well as their visual needs. The record of this information is precious and will enable the eye care professional to perform the visual examination in an orderly fashion, as well as know, before commencing the visual examination, the likely reasons for the symptoms (for example, the type of refractive error).

Firstly, it is important to understand the reasons for the consultation, by asking the patient a few open questions such as 'What is the reason for your visit?', 'What seems to be the problem?', or 'What visual problems do you have?'

Next, ask further questions to help specify the visual problem. For example:

- the exact nature of the problem: visual fatigue, blurred vision, double vision?
- the location at which the problem occurs: in the far distance, mid-distance, close up, centrally, peripherally, one eye or both?
- the circumstances in which the problem occurs: reading, working at a computer screen, driving?
- the time and the frequency of occurrence: morning, evening, intermittently, constantly, immediately or only after a long period of reading?
- the lighting conditions: in strong light, low lighting, night vision, sensitivity to glare?
- the date and mode of occurrence: when did it happen, was this the first time, sudden or gradual onset?
- the time of onset and nature of the problem: has the problem become better or worse, what solutions has the patient found to relieve or exacerbate the condition?
- etc.

During this discussion, the patient's answers may be restated in order to ensure that they have been properly understood. If need be, ask a few closed questions or suggest examples to clarify their responses.

In addition to the patient's personal details (name, date of birth, etc), you should note the visual history and more particularly all the details of the patient's previous glasses; this may be done either from the previous patient file, through information provided by the patient, or by measuring the prescription currently worn by the patient. This can be done either before or after performing the refraction; preferably after, so as to avoid potentially influencing the subjective refraction by having prior knowledge of the previous correction.

It is also vital to know how and when the patient will use their new glasses; in particular for which professional or leisure activities. Again, this should be determined by asking a few questions, such as:

- concerning professional activities: description of the activity or activities, working distance(s) required, position of work (for example: at, above or below eye level, directly in front or off to the side), lighting, surroundings, degree of attention required, duration of tasks, etc.
- concerning leisure activities: type(s) of sport, reading, do-it-yourself odd jobs around the home, driving, television, music, painting, sewing etc.

The ideal, in particular cases, is to be able to simulate the visual conditions of the situation(s) most frequently encountered by the patient, so as to ensure the visual correction prescribed is the most appropriate.

Finally, it is important also to find out about any special characteristics that could affect the patient's vision. Ask questions about their eye health: for example, family history of eye problems, eye infections, eye surgery, vision training undertaken, etc. Also ask about the patient's general health: diabetes, high blood pressure, allergies, injuries, medications taken, etc.

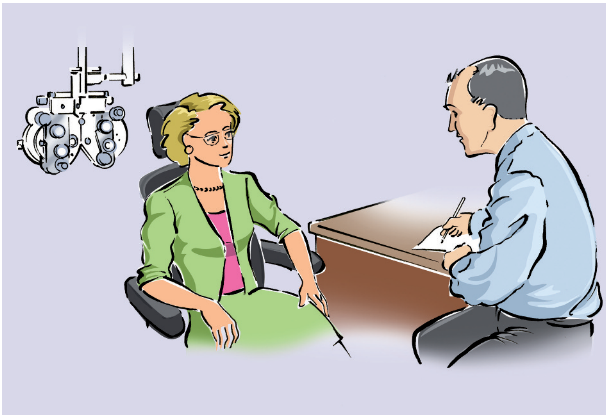


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Figure 12: The Preliminary Interview: An Essential First Contact

Recording the case history of the patient is of the greatest importance. The rigour and seriousness with which this first interview is carried out will give the patient confidence for the rest of the examination and provide key information for the eye care professional. By the end of the case history, the practitioner should have a good idea of the cause of the patient's symptoms and likely (refractive) findings and the most appropriate visual correction(s) for the patient.

B Preliminary Investigations

The first step in any visual examination is to perform a certain number of simple preliminary measurements. The practitioner should already have an idea of the refractive status of the patient's eye thanks to the case history; furthermore these measurements will help to identify and confirm the patient's visual problem(s). They also provide an opportunity to observe more closely the patient's behaviour.

Start by evaluating the patient's level of distance vision (without, then with, the current correction, monocularly then binocularly); next, evaluate their behaviour and reading capacity at near; then check ocular dominance and, finally, screen for binocular vision anomalies.

Distance Vision

A patient's distance vision is usually measured on a visual acuity chart placed at a distance of 4 - 6 m, without then with correction, monocularly then binocularly. The patient reads aloud the letters on the chart. Patients often tend to stop reading the first time they have trouble deciphering a letter. It is important to encourage them to continue by asking, for example, 'And what can you make out on the next line?' The level of vision achieved can be considered as the smallest line in which three out of five letters (or optotypes) are correctly recognised. Alternatively, on a logMAR chart, with the equivalent task of five letters per line and the regular progression of size between lines, each letter read correctly may be noted; each letter read correctly scores 0.02 of a logMAR unit, starting from the logMAR 1.0 (0.1 decimal) line.

There are many and varied visual acuity charts in existence and a variety of methods of the notation of visual acuity. For international simplicity, in this document, decimal notation will be used. (Please see the supplement "Visual Acuity" for a comparative list of different VA notations and a more detailed comparison of the different notations).

While the patient reads the VA chart, observe his/her behaviour: for example, be sure to avoid that the patient squints during vision measurement.

During monocular vision testing, it is important to make sure the occluded eye is not affected. It is preferable that the practitioner hold an occluder over the patient's eye in such a way that the eye is not touched and so as to avoid the patient's covering their eye with their hand and coincidently pushing on the eye or even closing their eye, all of which may affect the vision. Some consider that a translucent occluder is preferable to an opaque occluder, as observation may be made of the covered eye at the same time; however in general, this may be performed using the separate *Cover Test* (both unilateral and alternating) for a fuller evaluation (see later).

Accommodative and Convergence Function

It is essential to check the patient's accommodative and convergence function at near. To do this, identify:

- **the Near Point of Accommodation:** move a very small target (e.g. optotypes or small print) towards the patient (wearing their distance correction) until they can no longer see it clearly; note the distance; then, move the target away from the patient until they can see it clearly again; note the distance. These two positions should not differ by more than 1 or 2 cm. This measurement should be performed monocularly and binocularly. It is particularly useful in patients with pre-presbyopia to screen for accommodative dysfunction and in patients with anisometropia to demonstrate accommodative disparities between the two eyes. *(The remaining accommodation (in dioptres) may be estimated by this Push Up method, as it is the inverse of the closest distance (in metres) at which the patient can still see clearly (that is, the near point of accommodation). The measurement of the amplitude of accommodation by this method is simple but not the most accurate method of true amplitude of accommodation. However, for practical purposes and for this file, it suffices and gives a good working indication of the patient's accommodative function).*
- **the Near Point of Convergence:** have the patient focus on a fine target such as a pen tip or small print (both eyes open). Slowly move the target closer to their nose until the patient sees two targets instead of one (double vision) and/or you notice that one of the patient's eyes loses fixation (that is, deviates); note this distance *(break)* and which eye deviated. Now slowly move the target away from the patient until they can once again see the target singly and you notice that they regain fixation with both eyes *(recovery)*; note this distance. Repeat the test one or two times and note consistency or any large variation. Normally the break position is no more than 5-10 cm from the nose, the difference between break and recovery is only a few centimetres at most, and the measurements are very repeatable. If a patient's break point is at a distance >20cm or if it recedes very quickly as they fatigue with repetitions of the test, this is indicative of convergence insufficiency.

Near Vision

Have the patient hold a reading test card at whatever reading distance they naturally choose. Provide appropriate focal lighting. Ask the patient to read, aloud, smaller and smaller print until they have reached the smallest characters able to be read. As with the distance vision test, the patient should be encouraged to continue to read beyond where difficulty is first encountered. This measurement should be carried out using high contrast (100%) print, in good lighting conditions.

The test can also be performed with low contrast (10%) print: the difference between the two measurements should not exceed 1-2 paragraphs (size increment). A larger difference may be indicative of a refractive defect or a pathological problem.

Reading Distance

It is important to know the patient's usual or required working distance. This may vary considerably from one person to another; for example close precision work at 25 cm, work with different computer screen positions, or specific tasks such as reading sheet music. The visual environment may also vary widely. It is therefore important to understand fully the patient's main near tasks, by asking for detailed descriptions or even simulations. This way, you may tailor their visual correction to suit.

The reading distance varies in accordance with the patient's tasks and habits and often also in relation to their physical size. To check a patient's habitual reading distance, ask them to hold a reading test card where it feels comfortable to them; measure the distance from the eye to the card. This distance is usually comparable with *Harmon's Distance*, the distance from the elbow to the tip of the index finger when it is touched to the thumb (see Figure 13); this is a benchmark measurement which generally represents the reading or writing distance at which a person should be able to read comfortably. Observe whether the patient reads naturally at, closer than or further than this distance. This may provide further information regarding the patient's level of vision (weak or good), accommodative capacity (sufficient or not) and binocular behaviour (esophoric or exophoric). Finally, during this test check whether the patient reads centrally or tends to offset the text to the right or left.

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Figure 13: Reading Distance and Harmon's Distance

Dominant Eye

Before proceeding to refraction, it is useful to know which of the patient's eyes is dominant. Just as people are right- or left-handed, all generally have a preference for one eye. Use the CheckTest™ (Figure 14) to determine which eye is dominant. Have the patient hold the CheckTest™ at arm's length and look through the hole within it, with both eyes open, at a distant target. Occlude one of the patient's eyes at a time and have them compare the position of the target within the hole of the CheckTest™. The dominant eye is the one for which the target remains most centred when the other eye is occluded. The ocular dominance may or may not correspond with the patient's hand dominance. Knowing which eye is dominant has a threefold interest:

- some consider it preferable to start refraction with the non-dominant eye so the subject can 'practise' before the refraction of the dominant eye is determined;
- during binocular balance, if the perfect balance cannot be obtained, the dominant eye should be favoured;
- during dispensing, the centring of the lenses may be adapted to suit any strong lateralisation, as this may have an impact on the patient's head and eye posture when looking, particularly at near.

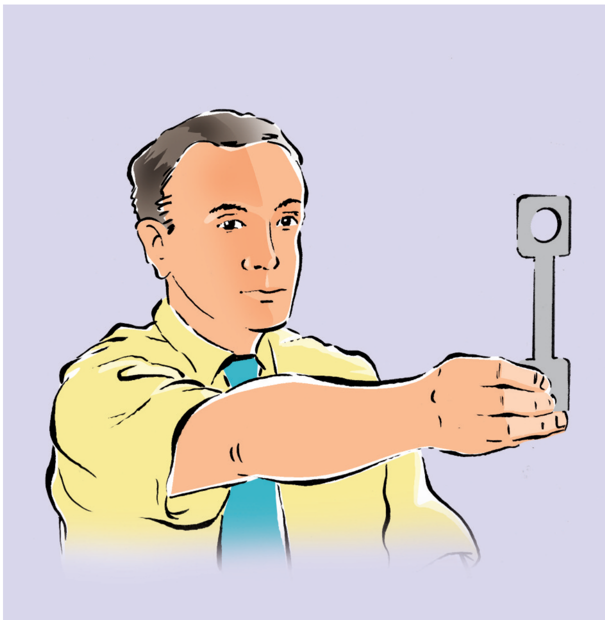

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Figure 14: Determining the Dominant Eye (using the CheckTest™)

Screening for Binocular Vision Anomalies

The following tests may be undertaken:

- **checking fusion by means of a red filter:** the aim is to assess the patient's level of binocular fusion by partially dissociating the images of the two eyes. Have the patient look at a distant point of light (for example, a pen torch at 5-6m). Place the red filter over one eye. If fusion is good, the patient will see only a single, pink light. If fusion is weak and thus disturbed, the patient will see either two lights (one white, one red in the case of complete dissociation of the eyes) or a single light (either white or red, depending on which eye is suppressed). If suppression is incomplete, the patient may see one light, alternating red and white (depending on which eye is suppressed). Perform this test by placing the red filter over each eye, one at a time. The point of light is seen as a darker pink ('more red') when the red filter is placed over the dominant eye.

- **screening for heterophoria or tropia with the Cover Test:** the aim is to check whether the subject has a latent deviation of the visual axes, for which they may have difficulty compensating. Have the patient focus on a target (this test should be performed both at distance and near). Place an occluder in front of one eye then remove it (*Unilateral Cover Test*). Observe if and how the eyes move under cover, immediately after having been under cover, and while the other eye is covered. Note the direction in which the eye(s) move(s) to recover fixation once the cover has been removed. If an eye realigns itself (to fixate on the target) via a temporo-nasal movement, the eye was turned out under cover and so the patient has an *exophoria*. If the movement is naso-temporal, the patient has an *esophoria*. If the eye does not move, the patient has *orthophoria*. The *unilateral cover test* should be performed by covering first one eye, then the other. The *alternating cover test* involves the transfer of the occluder directly from the first eye to the other, and back again, before uncovering and returning the patient to the binocular state. The movements of the eyes under cover and after removal of the cover, provide information as to the presence of phoria and tropia. The amplitude and speed of the movements (phorias or tropias) should also be noted. These findings constitute only a preliminary indication, as heterophoria poses a problem only if its compensation proves difficult.

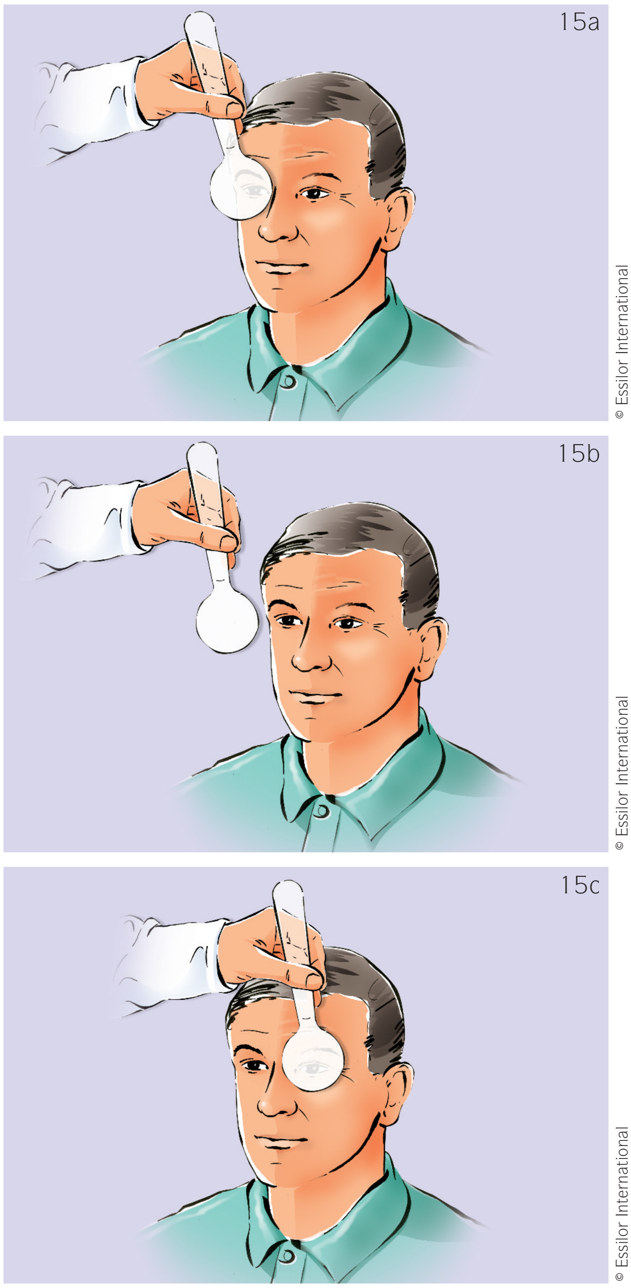

Figure 15: Screening for Binocular Vision Anomalies (using the Cover Test)

These preliminary measurements generally provide a wealth of information and usually allow some of the patient's problems to be identified before going on to perform refraction itself.

Supplement:

Visual Acuity

Visual acuity is, by definition, the capacity of the eye to distinguish the smallest details of a high contrast object; that is, its finest detail resolution achievable. It was defined by Dutch ophthalmologist Herman Snellen (1834-1908) as *the inverse of the angle, expressed in minutes of arc, subtended at the eye by the smallest detail that can be distinguished by the eye.* The human eye can, on average, discriminate between two points separated by an angle of 1 minute of arc (that is, 1/60th of one degree). That value (established by German ophthalmologist Hermann Von Helmholtz, 1821-1894) has been accepted as a universal benchmark. *(However, it is important to remember that even amongst a population of people with normal eyesight, there is a range of normal visual acuity and some will see finer detail than the 1 minute of arc average).*

It is important to note also that visual acuity is the measure of the eye's maximum ability to resolve detail of high contrast; it is a measure of the eye's maximum ability (the best achievable) and is therefore measured under ideal conditions, that is, maximum contrast, good lighting level and with best refractive correction. Therefore, visual acuity is noted at the end of the refraction; any measurements of vision with prior glasses, or without any refractive correction, are not measurements under best conditions and so are measurements of "uncorrected vision" or "vision with current correction/corrected vision" rather than a true measure of "best corrected visual acuity".

Distance Vision

In the ordinary refractive practice, the eye care professional determines *morphoscopic* or *image recognition* acuity (by having the patient read a variety of letters which they must recognise by discriminating the letter detail and recognising its shape), rather than actually determining the minimum discrimination of the eye, as is tested when using the E or C charts, for example (where the same symbol is used throughout the chart and so it is discrimination which is tested rather than letter recognition).

Visual acuity notation differs from one region of the world to another. Generally speaking:

- in Latin countries, the notation is decimal (0.1, 0.2, 0.3, ..., 1.0, etc.) or expressed in tenths (1/10, 2/10, 3/10,..., 10/10, etc.). It corresponds with the inverse of the angle subtended at the eye by the critical detail of the optotype: 10' of arc for 1/10, 5' for 2/10, 2' for 5/10, 1' for 10/10, etc.
- in English-speaking countries, the notation is expressed as a fraction of six (6/60, 6/36, 6/30,..., 6/6 etc.) or twenty (20/200, 20/120, 20/100, ..., 20/20 etc.) depending on whether the standard test distance is referred to in metres or feet (6 metres ~ 20 feet; 1 foot = 0.3048 m). This notation uses the Snellen fraction principle where the numerator represents the test distance and the denominator the distance at which the smallest detail of the optotype subtends an angle of 1 minute of arc at the eye (that is, the distance at which it can be deciphered by a subject with visual acuity of 1.0 (the reference benchmark for average, normal vision)). Thus acuity of 6/12 (20/40) indicates that the subject can read at 6 metres (20 feet) what a person with normal, average acuity of 1.0 can read at 12 metres (40 feet). For the same numerator (test distance), the larger the denominator, the worse the visual acuity. Calculating the Snellen fraction gives the decimal notation (for example, 6/6 = 20/20 = 1.0).

Conventionally, the height of an optotype corresponds to five times that of the detail to be distinguished: the thickness of the strokes of the characters and the gap of the letter C represent, for example, one fifth of the total height of the character (optotype). That is, the height of an optotype subtends an angle of 5 minutes of arc at the eye. Letter width may be 4 or 5 times the detail to be distinguished. There exist international standards which stipulate letter formats (for example, 5 x 4 and non-serif in form) and specify the optotypes or the limited selection of letters to be used, those being letters of similar legibility.

There are many types of visual acuity scale:

- depending on the type of optotype used: letters, numbers, the Landolt ring or C (1888), Snellen's E (1862), pictures, etc.
- depending on the progression of acuity values: scales may be *decimal* (Monoyer, 1875), *angular* (in minutes of arc (Mercier, 1944)), *inverse* (1/10, 1/9, 1/8 etc.), *rational*, (that is, inverse for the low acuities then decimal for higher acuities (Lissac, 1956)), or *logarithmic* (Bailey and Lovie, 1976).

This logarithmic scale presents an arithmetic progression by 0.1 unit step of the logarithm of the Minimum Angle of Resolution (MAR); in other words a geometric progression of $\sqrt[10]{10}$ = 1.259 of the MAR. This regular progression of size between each line of the chart means that the value of the angle is halved (doubled) every 3 lines and multiplied (divided) by 10 every 10 lines. (For example, descending from the large letters to the smaller, the size of the letters on every 3rd line is halved and so the acuity is doubled. Ascending from the smaller letters to the larger, the size of the letters doubles every 3 lines). This type of scaled chart offers a regular progression, flexible test distances, an identical number of optotypes (and therefore an identical visual task) on each line of the chart, a coherent choice of letters and simple conversion of the visual acuity measurement at all distances, and has therefore become an international standard (Figure 16).
Many acuity scales have been created by many authors; this is not an exhaustive list.

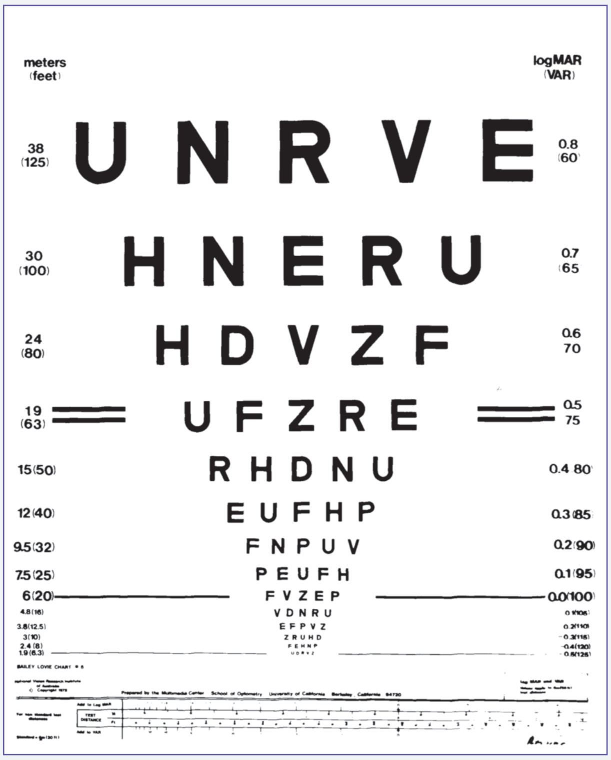

Figure 16: Logarithmic Acuity Progression Scale (Bailey-Lovie distance chart)

Published with the kind permission of Ian Bailey and Jan Lovie-Kitchin.

Original reference: *New Design Principles for Visual Acuity Letter Charts,* Ian L. Bailey and Jan E. Lovie, *American Journal of Optometry and Physiological Optics,* 1976.

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Near Vision

Two different approaches can be used to assess the visual performance of a patient in near vision: the patient's visual acuity can be measured by means of a near acuity scale, or the patient's reading capacity can be measured by texts using characters of different font sizes. (Note that the measurement of near visual acuity is a different task from the assessment of a patient's reading capacity; the latter may be more representative of day to day near visual function and activity).

Near Visual Acuity Scales

As with distance vision, there are many different near visual acuity scales. The most commonly used is the logarithmic progression scale, a near version of the scale used for distance vision.

The benefits of the logMAR system for near are those as outlined above, for distance assessment. On the Bailey-Lovie word reading chart, a variety of words of different lengths have been specifically chosen to ensure a consistent task at each line, and the text is composed of unrelated words rather than an extract of text, such that the patient is obliged to read each word rather than guess from the context of the sentence; this provides a more accurate assessment of their near acuity. Again, the regular progression of size between each line of the chart allows for easy conversion and flexibility of test distance and confidence of predictability of performance for changes in different factors. For these reasons the near logMAR chart is universally recognised and has particular application in research and low vision assessment. There exists also the Bailey-Lovie reading chart where the text forms a coherent sentence or phrase, to reflect a reading task.

Reading Capacity Measurement Scales

Scales and types of notation differ from country to country; only the most common methods are listed here:

- **Parinaud's scale and notation** (P notation): very widely used in French-speaking countries, this scale was developed in 1888 by French ophthalmologist Henri Parinaud. The scale is calculated for a distance of 25 cm, with an arbitrary 20% reduction in the size of the characters relative to distance vision scales (4' of arc of visual angle instead of 5'). This reduction is designed to take into account the effects of reduced pupil size for near vision and thus render the scale comparable to the distance visual acuity test. Each paragraph corresponds to acuity of 1.0 for the reference distance and so permits near visual acuity to be estimated in accordance with the distance, by the ratio of reading distance/reference distance (the reference distance being equal to 0.25 m x Parinaud Number). Thus:

  - if P1, P2, P4 are read at the reference distances 0.25 m, 0.50 m, 1.00 m, respectively, this corresponds to an acuity of 1.0 (10/10).
  - If P4 is read at 50 cm acuity is 0.50 m / (4 x 0.25 m) = 0.5 (5/10), and if P1.5 is read at 45 cm acuity is 0.45 m / (1.5 x 0.25 m) = 1.2 (12/10).

  Many versions of this scale have been published. It is used today more out of tradition than for its qualities of precision and simplicity.

- **Scale and notation in typographic points** (N notation): used predominantly in English-speaking countries, this scale uses standard typographic units (font sizes). It uses the 'Times Roman' typeface and the paragraphs are graduated according to the size of the characters, expressed in typographic points (N5, N6, N8 etc.). Near reading performance is noted by N (for 'Near'), followed by the size of the character, along with the reading test distance (for example, N5 at 40cm). The advantage of this test is that reading performance is assessed on exactly the same types of printed material as those the patient is likely to encounter in daily life.

- **Jaeger scale and notation** (J notation): often used in the United States of America, this scale also uses typographic characters with a notation depending on the size of the typeface font. The notation is, for example, J1, J2, J3, etc, the J being from the name of its inventor (Viennese ophthalmologist Eduard von Jaeger, who developed this system in 1854) and the number indicating the size of the font. Unfortunately, the sizes of the characters are not standardised. There have been numerous variants of this scale with arbitrary graduations and variable character sizes. Despite its imprecision, it is still in extensive use.

- **Metric scale and notation** (M notation): this system was developed by two American research scientists, Louise Sloan and Adelaide Habel, in 1956. The size of the characters is described by the letter M preceded by a number which is the distance in metres at which the characters subtend at the eye an angle of 5 minutes of arc. The detail to be distinguished is conventionally equal to one fifth of the height of the character. Therefore, for example, the notations 1.0M and 0.50M mean that visual acuity is 1.0 at the distances of 1.0 m and 0.50 m, respectively. The size of the letters is specified in M units corresponding to a height 1.45 mm: thus, 1.0M corresponds to a character of height 1.45 mm, 0.50M to 0.725 mm, etc. To know the M value of a text, simply divide the height of the letters by 1.45. This M unit also corresponds to the acuity denominator expressed as a Snellen fraction. This type of notation is internationally recognised, is simple and practical and has proven to be particularly useful in low vision assessments.

The common thread amongst these different near scales is, similarly as for distance visual acuity, the patient's visual performance is assessed by noting the size of the smallest characters deciphered, necessarily accompanied by the test distance used. For example, P1.5 at 37 cm, N5 at 40 cm, J2 at 40 cm or 0.4M at 40 cm are considered as good levels of near vision.

3. Objective Refraction

Start the refractive examination by determining the objective refraction, so called because it does not rely on any input from the patient. To determine the objective refraction, the eye care professional can use either the technique offered by auto-refractors, or the classic technique of retinoscopy. Whatever the method used, objective refraction should always be performed, but can constitute only an *initial approach to refraction* which must be confirmed subsequently by a subjective refraction examination. Only in exceptional circumstances, where subjective refraction is impossible, such as in the examination of a baby, young child, or another patient who is unable to communicate, should the objective refraction be used for the final prescription.

A Auto-Refractometry

Automatic refractometry is a quick and easy way of obtaining an objective measurement of the patient's refraction.

The patient places their head in the appropriate chin and forehead rests of the instrument, so as to be still, and then fixates on the target inside the instrument, whilst blinking normally as required. The practitioner then moves the instrument until it is centred on the patient's eye and the image of the eye is focussed. When this is the case, the measurement may be taken automatically or manually, depending on the mode selected. A series of measurements is taken and the average value is calculated. The process is repeated for the other eye and results may then be printed.

Most auto-refractors operate on the principle of the emission of an infrared light beam. An opto-electronic sensor captures the image of this beam after it has been reflected by the retina and has passed through the eye twice (that is, upon entry and exit). This image is processed and analysed by computer software and the refraction value is extracted. Different optical principles are used depending on the instrument. For further details please refer to the technical data supplied by the instrument manufacturer.

Despite the progress achieved, auto-refractors do not yet provide a perfectly reliable measurement of refraction. The sphere is often over-minussed (that is, myopia is over-estimated and hypermetropia under-estimated) because of the stimulation of accommodation when looking inside the instrument (*instrument myopia*). Indeed, the higher the degree of ametropia, the greater the degree of imprecision. This is why it is important to ensure that the patient is properly relaxed during the measurement and to use the result only as a first step in determining the patient's refraction. The cylinder too is often over-estimated and the precision of its axis (often to the degree) is sometimes falsely excessive. The fixation and attentiveness of the patient may also affect the precision of the measurement. The art of the practitioner lies in being able to manage these factors in order to obtain a useful measurement, which is indeed more difficult to achieve than it might appear.

Auto-refractors also often integrate a keratometry measurement. As well as the obvious application that this measurement has to the fitting of contact lenses, it can also be used to assess whether the patient's ametropia is more *axial* or *refractive*.

While it is not desired to discredit the contribution of these instruments in any way, it is important to state clearly that the auto-refractometry measurement alone cannot suffice to determine a patient's refraction and that, where possible, **it should always be complemented by a subjective examination.**

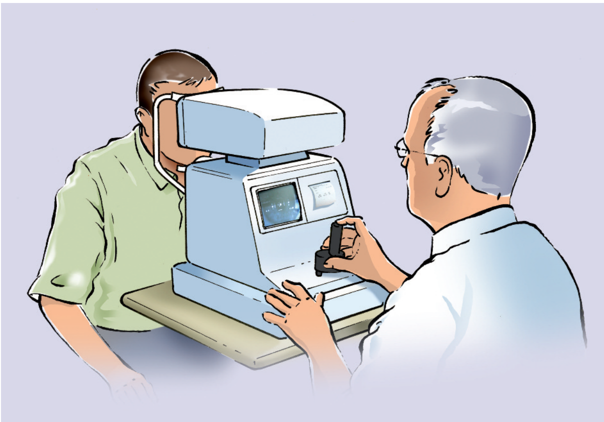

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Figure 17: Auto-Refractor

B Retinoscopy

Retinoscopy (or *skiascopy*, from the Greek *skia* = shadow and *skopein* = examine) is a technique which permits an estimation of the refractive status of an eye, based on the movement of the light reflex from the eye, as observed through an optical instrument known as a *retinoscope*. It was introduced at the end of the 19th century by Ferdinand Cuignet, a French military ophthalmologist (1823-1889). Being an objective technique, it does not require any patient input and is therefore useful as a pre-subjective refraction tool for all patients, but particularly infants and those unable to communicate. It also provides incidental information about the clarity and regularity of the ocular media and hence the anticipated level of vision.

Retinoscopy was derived from ophthalmoscopy and is similar to the technique of manual lens neutralization (and the fundamentals of vertometry/lensometry/focimetry). The light from the retinoscope is shone into the patient's eye and the retina acts as a reflective screen over which the light is moved; the light reflected from the retina (now acting as a secondary light source) and hence out of the eye is called the "reflex" (as with the red reflex through the pupils in a flash photograph). The retinoscope is tilted such that its light sweeps across the eye; in comparison to the movement of the light from the retinoscope, the reflex will move in the same direction ("with" movement) or in the opposite direction ("against" movement).

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Figure 18: Retinoscope

The direction, speed and brightness of the reflex are related to the refractive error (the brighter the reflex and the faster its speed, the lower the refractive error). The observer assesses the form, movement and brightness of the reflex and places appropriate lenses in front of the eye until the speed of movement of the reflex is infinitely quick ("reversal"). The power of the lens at which reversal is achieved is the amount which neutralizes the refractive error of the eye. In the case of astigmatism, neutralization is determined independently in each principal meridian.

A *working distance lens* (generally either +1.50D (67cm) or +2.00D (50cm)) must be placed in front of the eye during retinoscopy to account for the fact that the observation is made through the retinoscope which is not at optical infinity. This working distance lens must be considered separately from the power of the lens at which neutralization occurs.

The most common kind of retinoscopy is *static retinoscopy* as outlined above. Within this there are two different kinds: *spot* and *streak* (depending on the form of the light shone from the retinoscope). There are also other, less common techniques by which retinoscopy may be used, including *Mohindra* Near *Retinoscopy* and *Dynamic Retinoscopy*, which may provide an assessment of the refractive and accommodative status at near.

Accommodation must be stabilized during retinoscopy and for this reason it is performed in the dark and the patient is given a distance target to observe. The size of the target is large, so it may be seen through the blur caused by the working distance lens. Cycloplegia may also be induced prior to performing retinoscopy and this is particularly useful when assessing young children and patients with large amounts of latent hypermetropia.

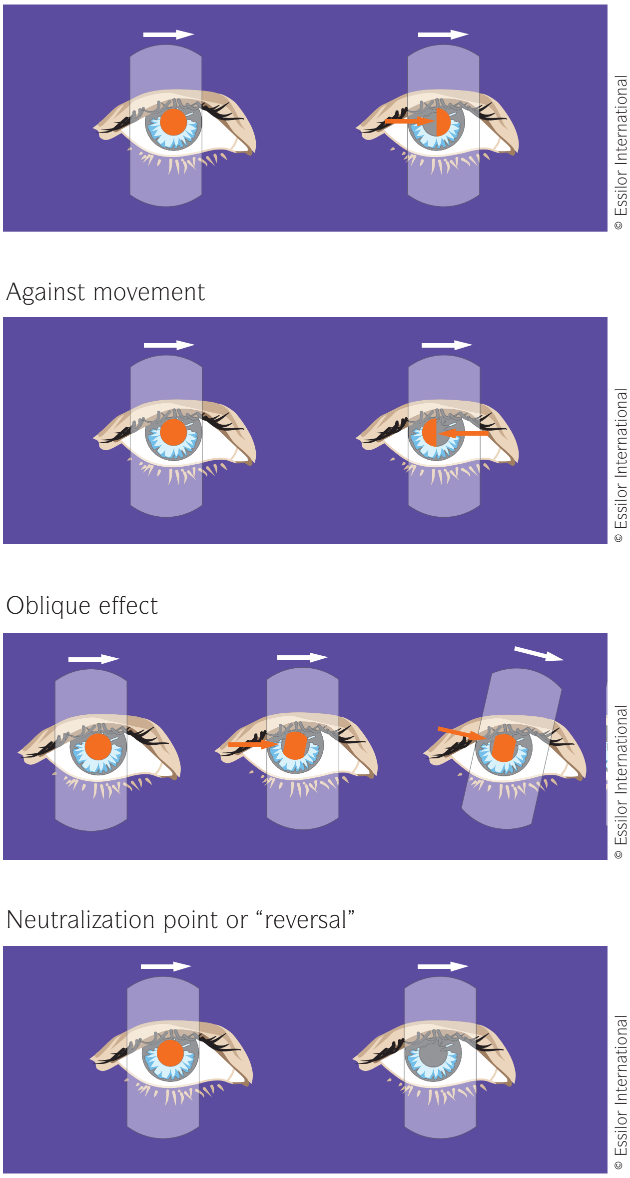
Figure 19: Different Reflex Effects in Retinoscopy

With movement

Against movement

Oblique effect

Neutralization point or "reversal"



The use of retinoscopy requires experience which may be acquired only by regular practice. Although the technique takes longer to master than that of auto-refractometry, it can prove just as efficient and at times more practical.

4. Subjective Refraction Distance Vision

Subjective Refraction is a technique used for determining the refractive error of the eye and involves the patient's ability to discern changes in the clarity of the test object when different lenses are placed in front of their eyes. By definition, it requires patient input.

Subjective Refraction will usually be performed as a check and "fine tuning" following an initial, objective assessment of the refraction. The starting point may be the objective refraction result or a previous prescription. Subjective refraction is performed monocularly at first, then verified in the binocular state thereafter. The recommended order for the process of performing subjective refraction is: monocular determination of the sphere, cylinder axis and power of each eye, followed by performance of binocular balance. Minus cylinders should be used.

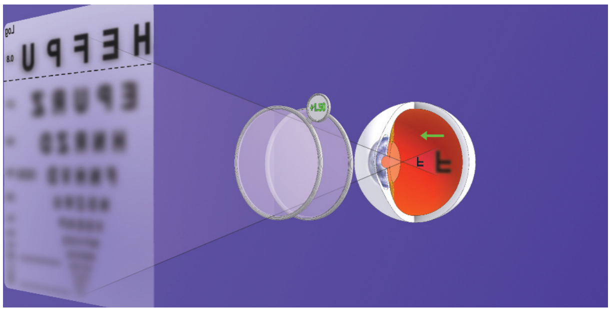
The method described below is a proven method, but just one of many possible methods of subjective refraction.

A Determining the Sphere

The so called 'fogging' method may be used to find the sphere. The idea behind this method is that a blur or 'fog' is created initially, with the aim of relaxing the patient's accommodation. This may be achieved because the patient will experience even greater blur if they accommodate, and so they gradually relax their accommodation to minimise the blur. The method involves placing a (plus) lens in front of the patient's eye so as to bring the retinal image forward and in front of the retina, causing blur, then gradually reducing the power of this lens until the image is brought back into focus on the retina. The most suitable level of fog has been determined to be that which reduces the patient's vision to the level of ~0.16 (generally ~+1.50DS); any greater blur than this may induce accommodation to the tonic level, rather like the accommodative tone exhibited in dark focus, and less blur may not control accommodation sufficiently.).

Figure 20: Principle of the 'Fogging' Method

a) fogging with +1.50D



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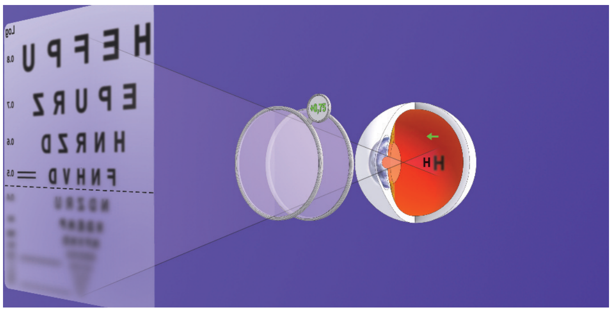
b) fogging with +0.75D



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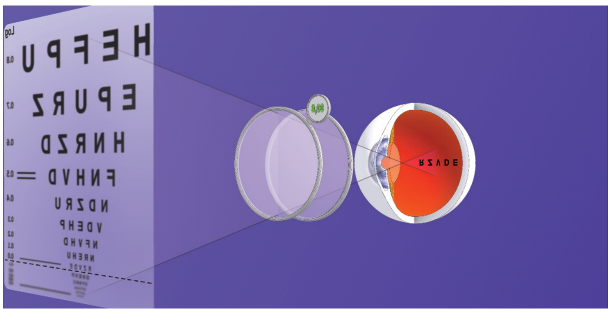
c) with the best vision sphere in place



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The sphere is firstly determined monocularly. Many practitioners perform refraction in the standard order of right eye then left eye (then binocularly), and this has the advantage of minimising transcription errors when noting results. Others believe it is helpful to perform refraction on the non-dominant eye firstly, so the patient may learn the technique and be sure to give good responses for the dominant eye tested thereafter.

This method is detailed below:

1) Place the starting correction (objective refraction or previous prescription) in front of the patient's eye (occlude the other eye) and measure and record the corrected vision.

2) Fog (blur the patient) by adding +1.50 D (For this power of sphere, vision would be expected to drop to ~0.16)

a. If vision is now better than 0.16, the patient is insufficiently fogged, implying that the initial correction was insufficiently plus; fog by further increments of +0.25D until vision is reduced to the ~0.16 level.

b. If vision is now worse than 0.16, this implies that the initial correction was excessively plus or insufficiently minus; start to remove fog, in increments as detailed below.

3) Remove fog progressively in steps of 0.25 D (that is, add -0.25D per step) and check at each step that vision improves (by approximately one line per 0.25D)*

* Theoretically, each 0.25D reduction of fog should improve vision by one graduation on the inverse acuity scale (known in France as "Swaine's Rule") in accordance with the theoretical sequence below for spherical ametropia (or the spherical equivalent of the ametropia in the case of astigmatism). The rule: ametropia = sphere value – 0.25 D / level of vision (see table). *The example given is that of an emmetropic eye with initial correction of plano and average normal visual acuity of 1.0:*

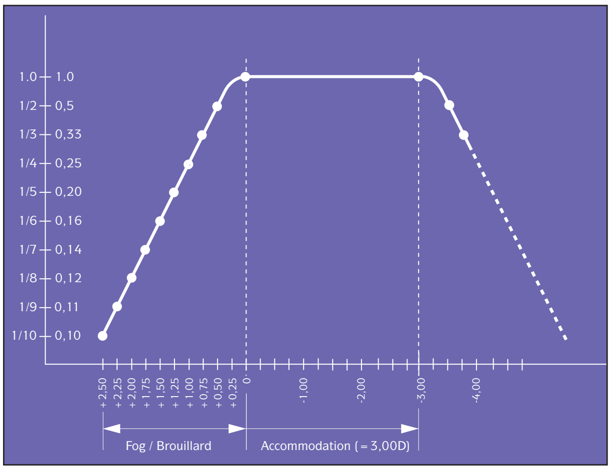


Figure 21: Level of Vision and Removal of the Fog

Fog (on top of starting refraction)	Acuity as fraction	Acuity as decimal	Effective ametropia with fog in place
+ 1.50 D	1/6	0.16 = 1.6/10	Sph -1.50 D
+ 1.25 D	1/5	0.2 = 2/10	Sph -1.25 D
+ 1.00 D	1/4	0.25 = 2.5/10	Sph -1.00 D
+ 0.75 D	1/3	0.33 = 3.3/10	Sph -0.75 D
+ 0.50 D	1/2	0.5 = 5/10	Sph -0.50 D
+ 0.25 D	1/1	1.0 = 10/10	Sph -0.25 D

During removal of the fog:

- if vision does not improve (or worsens) when the power of the fogging lens is reduced by a further 0.25 D, the patient may have accommodated by 0.25 D (or more). In this case, wait a few seconds to allow the patient to relax accommodation and check their vision again.

- check that the improvement in vision is consistent with that expected; the level of vision can be used at any time to estimate the effective ametropia with the fog in place, in accordance with Swaine's rule

4) Continue to remove fog until the level of vision does not improve further; that is, until the level of vision reaches a plateau.

5) Return to the sphere prior to the last removal of fog that did not give an improvement in vision; that is, select the most plus (least minus) sphere giving maximum vision at this stage (in order to prevent the retinal image from shifting back behind the retina, so allowing the patient to accommodate). Bear in mind also the sphere expected from the level of uncorrected vision and consider if it is consistent with this finding. (At this point, if starting from plano rather than the objective refraction result, the sphere is the *Best Vision Sphere*, and the vision is the best achievable with a spherical correction alone).

B Determining the Cylinder

After determining the sphere, the next step is to determine the power and axis of the cylinder. The cylinder axis is determined firstly, followed by the cylinder power

The method detailed below uses the Jackson Cross Cylinder. During this procedure it is best to have the patient look at a round target; for example, either a letter O (of appropriate size for their level of vision) or the cluster of round dots available on many projector charts.

Jackson Cross Cylinders are available in powers including $\pm$0.25D and $\pm$0.50D. The $\pm$0.25D cross cylinder will permit a more accurate result but it will be more difficult for the patient to discern the difference between the images during refraction. Some consider it most appropriate to use the $\pm$0.25D at all stages, changing to the $\pm$0.50D only when the patient has impaired vision and is unable to distinguish between the images presented. Others consider the $\pm$0.50D should be used when determining the cylinder axis and the $\pm$0.25D when determining the cylinder power.

USING THE OBJECTIVE REFRACTION OR PREVIOUS PRESCRIPTION AS A STARTING POINT

1) Determining the cylinder axis:

Have the patient look at a letter (of a size appropriate for their level of vision), preferably a round letter such as an O, or the cluster of dots, throughout the duration of using the cross cylinder.

a. **Position the handle of the cross cylinder along the axis of the corrective cylinder** (in the trial frame or phoropter). Advise the patient that it is normal for this to cause a worsening of the vision. This is the position 1 of the cross cylinder.

b. **Twist the cross cylinder quickly** (around the axis of its handle) so as to present the alternative view, position 2. Ask the patient to indicate which of the two positions offers clearer vision (that is, a sharper, blacker, rounder target) by asking a question such as "Which view gives rounder, clearer, sharper dots?" or "Which view is less blurred, 1 or 2? ...or are both views equally blurred?"; note the location of the negative axis of the cross cylinder for this preferred position
Remember that the patient's vision is blurred slightly by the cross cylinder and so both positions may be blurry; reassure the patient that you seek to know which view is clearer, or more correctly "less blurred".
You may need to repeat the presentations of positions 1 and 2 by continuing to twist the cross cylinder and presenting the two positions, to allow the patient several views to help them decide between them, particularly if the difference is minimal. Sometimes both views may appear equally blurred to the patient.

c. **Change the axis of the (minus) corrective cylinder by 5°**, turning it towards the location of the preferred minus cross cylinder position.

d. **Repeat steps a to c until the patient can see no difference or almost no difference** between the two positions (views). The corrective cylinder is now lined up along the correct cylinder axis (that is, the axis of astigmatism), as is the handle of the cross cylinder.

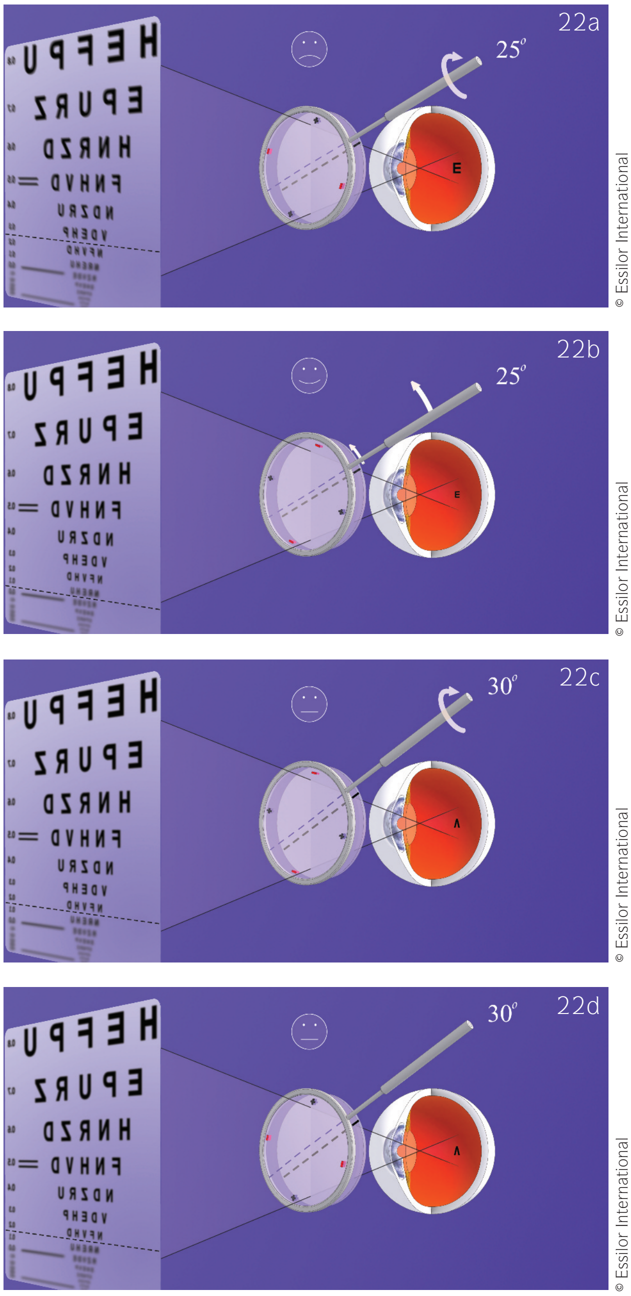


Figure 22 a, b, c, d: Determining the Cylinder Axis

2) Determining the cylinder power:

a. **Position the negative axis of the cross cylinder along the axis of the (minus) corrective cylinder**. This is position 1.

b. **Twist the cross cylinder** to present position 2 and ask the patient to indicate which position gives clearer (less blurred) vision.

c. **If the patient prefers** position 1 (minus axis of the cross cylinder along the axis of the minus corrective cylinder), it indicates they prefer more minus cylinder, so increase the minus corrective cylinder by -0.25D. If position 2 is preferred, it indicates they prefer less minus, so remove -0.25D.

d. **Repeat steps a to c until the patient has no or virtually no preference** or the preference is reversed. This is the cylinder power of the refraction.

So as to maintain the spherical equivalent, remember to adjust the sphere power by +0.25DS for every extra -0.50DC cylinder added, and by -0.25DS for every extra -0.50DC removed.

If hesitating between two cylinder powers (that is, if the patient does not reach a point at which the two choices are exactly equal), err on the side of prescribing the lesser (minus) cylinder power.

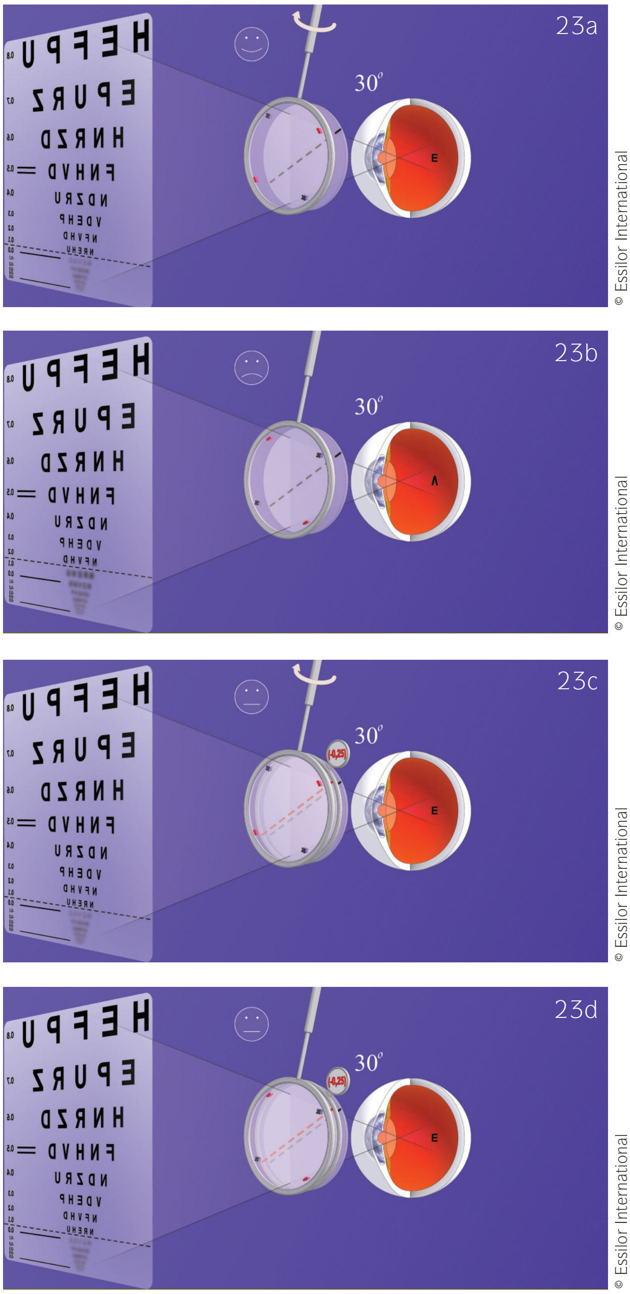


Figure 23 a, b, c, d: Determining the Power of the Cylinder

WITHOUT PRIOR KNOWLEDGE OF THE REFRACTION

1) Determining the cylinder axis

The following bracketing method may be used:

a. **Position the handle of the cross cylinder along the horizontal axis** (such that its principal meridians are along 45° and 135°). This is position 1. Twist the cross cylinder to present position 2 and ask the patient to indicate which position gives clearer (less blurred) vision; note the orientation of the negative axis of the cross cylinder for this preferred position (either along 45° or 135°).

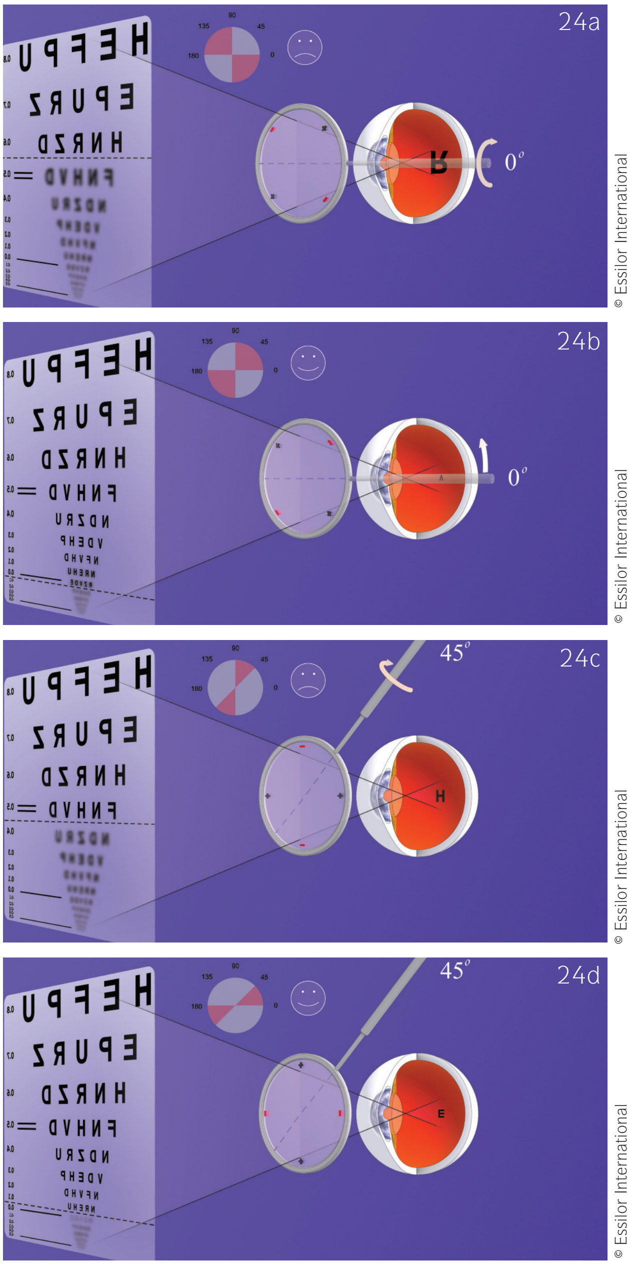
b. **Now position the handle of the cross cylinder along 45°** (handle along 45°, meridians along 180° and 90°). This is position 1. Twist the cross cylinder so as to present position 2 and ask the patient to indicate which position gives clearer (less blurred) vision; note the orientation of the negative axis of the cross cylinder for this preferred position (either along 180° or 90°).

By combination with the previous measurement (results of steps a and b together), the cylinder axis of the patient's refraction is now known to be located within a 45° sector.

c. **Position the handle of the cross cylinder along the bisector of the 45 sector identified** (or, with experience, nearer the axis for which the subject has expressed the clearer preference). Twist the cross cylinder and ask the patient which view they prefer.

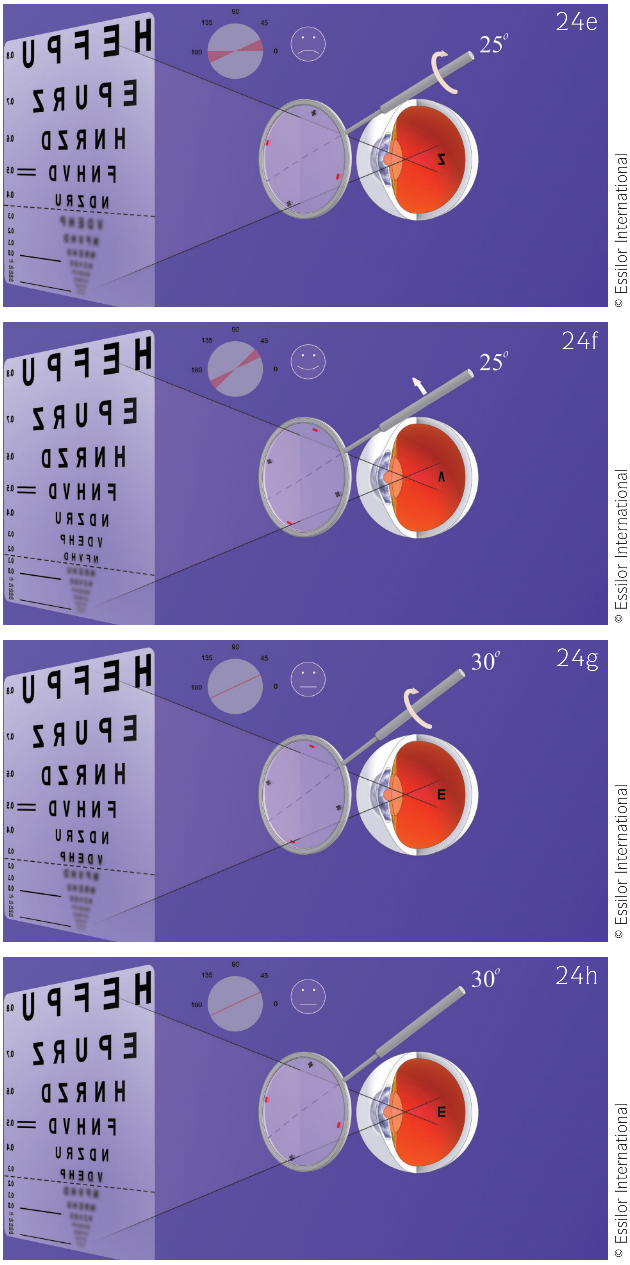
d. **Rotate the axis of the minus corrective cylinder 5°** in the direction of the minus axis of the preferred cross cylinder (or place it at the bisector of the residual angle between the handle of the cross cylinder and the limit of the 45° sector).

e. **Repeat steps c and d until the patient has no preference** or almost no preference of the two views presented. The position of the handle of the cross cylinder now indicates the corrective cylinder axis.



a, b, c, d: Localization of the cylinder axis within a 45° sector

Figure 24 a to l: Determining the Cylinder Axis (without prior knowledge of the refraction)



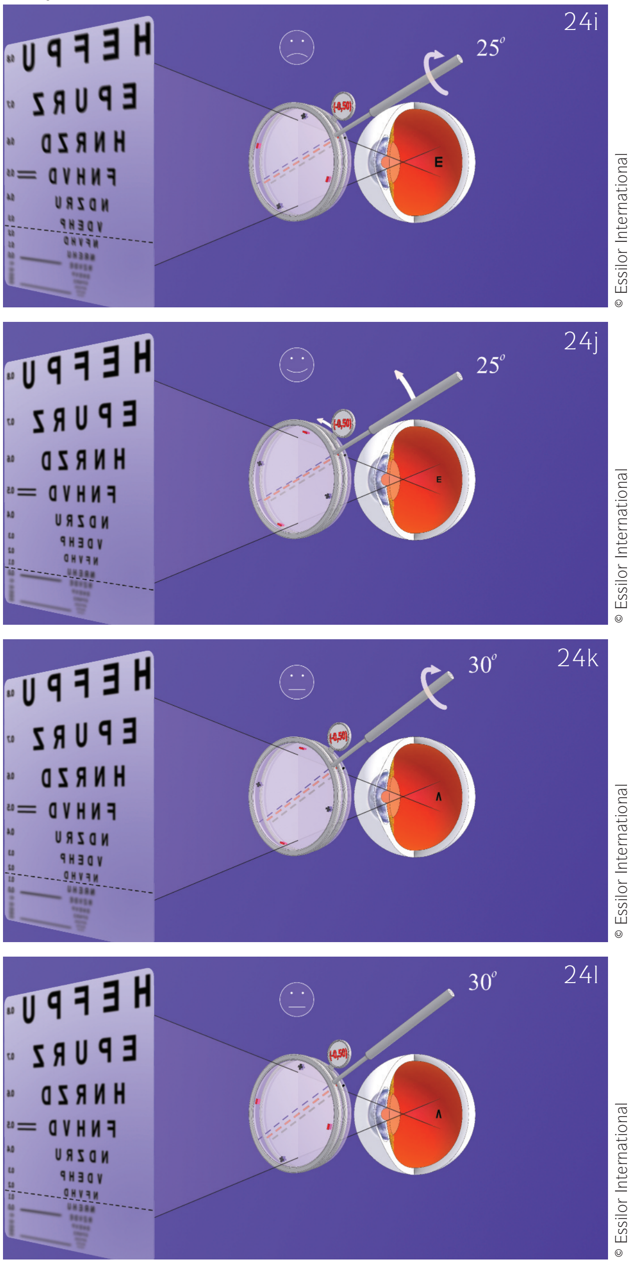
e, f, g, h: Determining the cylinder axis using the cross cylinder alone

Alternative technique:

c. **Place a -0.50D corrective cylinder in the trial frame or phoropter**, at an axis located in the middle of the 45° sector identified.

d. **Position the handle of the cross cylinder along the axis of this cylinder** (this is position 1); twist the cross cylinder to present position 2; ask the patient to indicate which position gives clearer (less blurred) vision and note the location of the negative axis of the cross cylinder, for the patient's preferred position. Rotate the axis of the corrective cylinder by a small increment towards the axis of the negative cylinder of the cross cylinder.

e. **Repeat step d until the patient has no preference** or almost no preference between positions 1 and 2. The corrective cylinder is now aligned along the cylinder axis of the patient's refraction.



i, j, k, l : Determining the cylinder axis using a trial cylinder and the cross cylinder

2) Determining the cylinder power:

Proceed as detailed above, considering the starting point as the best vision sphere (in place) and the -0.50D corrective cylinder (in place) used to refine the cylinder axis.

Have the patient continue to fixate on the cluster of dots or a round optotype on the distance chart. The power of the corrective cylinder will be adjusted progressively in steps of -0.25 D as the patient is presented the different views using the cross cylinder.

a. **Position the cross cylinder such that its minus axis is along the axis of the (minus) corrective cylinder.**

b. **Twist the cross cylinder** to present the two views and ask the patient which position they prefer.

c. **If the patient prefers** the position with the minus axis of the cross cylinder in line with the minus axis of the corrective cylinder, add more minus (-0.25) D to the corrective cylinder; otherwise remove -0.25 D. *Remember also to maintain the spherical equivalent - adjust the sphere power by +0.25DS for every extra -0.50DC cylinder added, and by -0.25DS for every extra -0.50DC removed.*

d. **Repeat steps a to c until the patient has no preference** between the two views of the cross cylinder, almost no preference or their preference is reversed.

e. **Select the value of the weakest minus corrective cylinder** giving maximum vision.

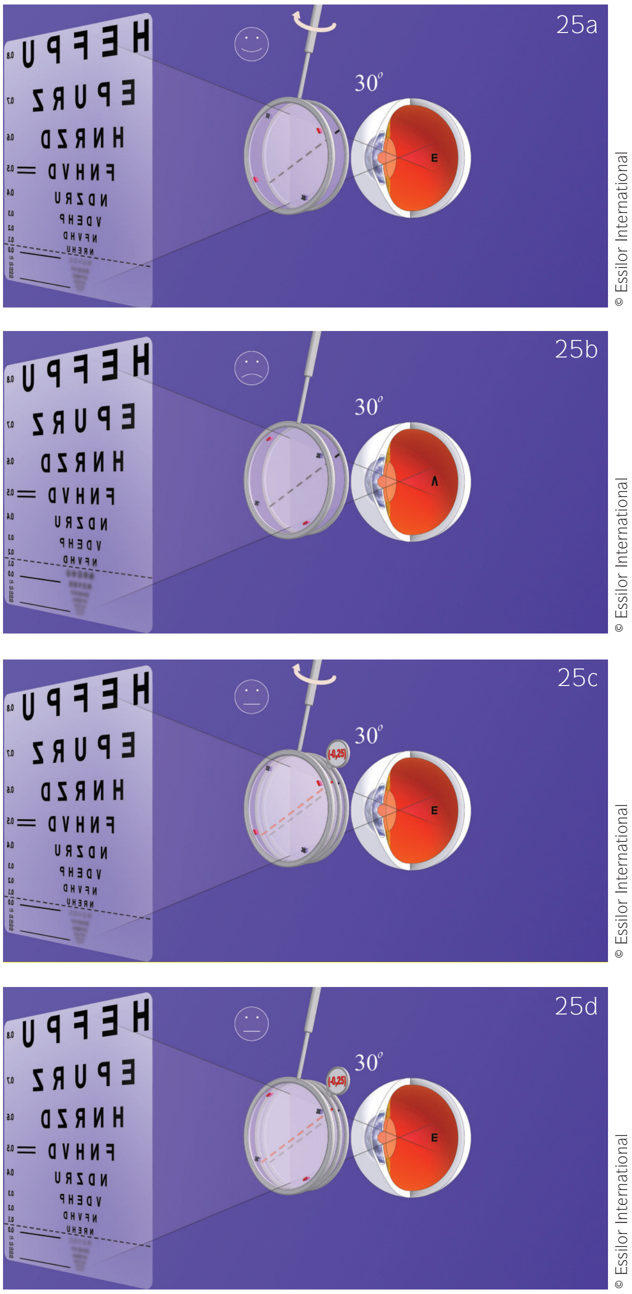


Figure 25 a, b, c, d: Determining the Cylinder Power

AFTER DETERMINING THE CYLINDER

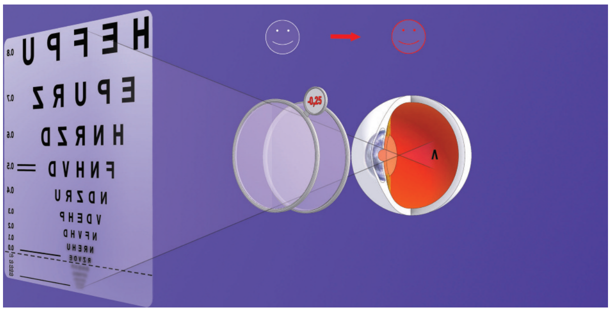
3) Final check of the sphere

Once the axis and the power of the corrective cylinder have been determined, proceed to a monocular verification of the sphere by means of + and -0.25 D spherical lenses in order to confirm that the sphere obtained is actually the 'maximum plus offering maximum visual acuity'. Thus:

- with an extra +0.25 D, vision should be slightly reduced; if it is not, add the +0.25 D and repeat the checking of the sphere;
- with an extra -0.25 D, vision should remain the same (or be slightly reduced).

Figure 26: Final Monocular Verification of the Sphere

a) with +0.25 D: vision is reduced



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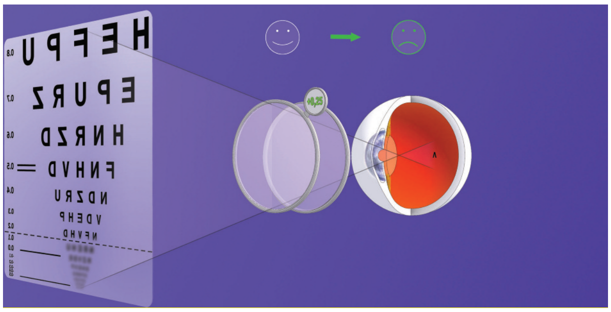
b) with -0.25 D: vision remains the same



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An Astigmatic Prescription Should Always Be Determined in Negative Cylinder Form

An astigmatic correction can be expressed in either positive or negative cylinder form. However, the prescription is normally determined as a negative cylinder. The 'fogging' method described above involves blurring the patient's vision by positioning both foci (of the principal meridians of the astigmatism) in front of the retina, then moving them back by gradually adding negative spheres in order to place the more posterior focus on the retina and subsequently merging the two foci into a single point by using a negative cylinder to move the more anterior focus posteriorly.
Depending on the country, however, practitioners and manufacturers may express the prescription in positive or negative cylinder form. The process of transposition allows the conversion from plus cylinder form to minus cylinder form and vice versa.

Transposition of a Sphero-Cylindrical Prescription

To transpose a prescription from plus to minus cylinder form and vice versa:
Step 1) the algebraic sum of the sphere + the cylinder gives the *new sphere*
Step 2) change the sign of the cylinder => this gives the *new cylinder*
Step 3) change the axis of the cylinder by 90° (by either adding or subtracting 90° as required so the result is between 0° and 180°) => this gives the *new cylinder axis*

Example
To transpose -2.00 / +3.00 x 105 to minus cylinder form:
Step 1) (-2.00) + (+3.00) = +1.00 (the *new sphere*)
Step 2) +3.00 becomes -3.00 (the *new cylinder*)
Step 3) 105 – 90 = 15 (the *new axis*)
so this prescription written in minus cylinder form is +1.00 / -3.00 x 15

(Note that by convention, the degree symbol is not written in a prescription; this is to avoid possible confusion. For example, 18° may be confused with 180 and vice versa).

Estimating the Refractive Error from the Level of Uncorrected Distance Vision

The spherical equivalent of a patient's refractive error may be estimated from their level of uncorrected distance vision. Although attributed in France to the English physicist and optometry teacher William Swaine (1894-1986) and called *Swaine's Rule*, the rule is not known by this name in the English-speaking world. The rule stipulates that the level of vision is reduced by one step on an inverse scale (1/1, 1/2, 1/3, ¼, etc.) for each

Level of Vision (decimal)	Level of Vision (inverse scale)	Expected Ametropia (spherical equivalent)
1.00	1/1	0.25 D
0.50	1/2	0.50 D
0.33	1/3	0.75 D
0.25	1/4	1.00 D
0.20	1/5	1.25 D
0.16	1/6	1.50 D
0.14	1/7	1.75 D
0.12	1/8	2.00 D
0.11	1/9	2.25 D
0.10	1/10	2.50 D

0.25DS of spherical refractive error. Thus a myopic patient with refractive error of -0.50 D is expected to have uncor rected vision of approximately 1/2 (0.5), a myopic patient with refractive error -0.75 D uncorrected vision of 1/3 (0.3) and so forth (see table).

This rule allows the practitioner to estimate the patient's refractive error from their level of uncorrected distance vision and hence have an idea of the expected prescription before starting objective and subjective refraction. Also, during refraction using the fogging method, (which involves rendering the patient effectively myopic by the addition of a plus lens), the rule can be used to assess the spherical blur created and thus anticipate the value of the final ametropia of the subject. For example, if during the initial fogging, the patient's vision is 1/6 (0.16), it can be estimated that the patient's ametropia is equal to the value of the fogging sphere – (6 x 0.25D) = +1.50 – (1.50D) = plano; if vision is 1/5 (0.20), the patient's ametropia is ~ +1.50 – (5 x 0.25D) = +1.50 - 1.25 = +0.25D. The rule allows changes in vision to be monitored during fogging and removal of the fog. This rule is most effective for myopic refractive errors and less consistent for hypermetropia or astigmatism. It is not always a precise rule but may be used as a good guide, allowing the practitioner to assess the consistency of the expected level of the patient's ametropia with the final refraction found.

The Jackson Cross Cylinder

Determining astigmatism by the cross cylinder method was made popular at the beginning of the 20th century by American ophthalmologist Edward Jackson (1856-1942). The cross cylinder is a sphero-cylindrical lens, the spherical equivalent of which is plano. The principle of the technique is to place the cross cylinder in front of the patient's eye and study the variations in vision that result from the combination of the astigmatism of the eye and that of the cross cylinder placed in different positions.

A cross cylinder is a lens that combines two plano-cylindrical lenses of identical powers but with opposite signs. The cylinders' axes are perpendicular to each other (hence the name 'cross cylinder'). A ±0.25 cross cylinder (that is, a cross cylinder created by combining +0.25D and -0.25D cylinders) is a +0.25/-0.50 lens; a ±0.50 cross cylinder is a +0.50/-1.00 lens. This lens is mounted in a special frame, the handle of which bisects the cylinder axes, such that the positive and negative axes of the cross cylinder may be easily swapped, by twisting the handle (Figure 27).

When placed in front of the patient's eye and so combined with the astigmatic eye, the cross cylinder accentuates or reduces the astigmatism and consequently causes variation in the level of the patient's vision. The cross cylinder is twisted and so its two positions presented to the patient, who is then asked to indicate which position gives the better vision. The cross cylinder is used in two different aspects of subjective refraction: determining the cylinder axis and the cylinder power of the patient's refraction.

Detailed procedures for using the cross cylinder are described above.

Figure 27: Jackson Cross Cylinders

The Duochrome Test

The Duochrome Test may be used to check the spherical correction. It makes use of the natural axial chromatic aberration of the eye which causes light of different wavelengths to be refracted differently by the eye. Longer wavelengths (perceived as red) are refracted less than shorter wavelengths (perceived as green) and so "red" light will be focussed more posteriorly than "green" light. (This gives rise to a range of focus rather than a true point of focus on the retina. The eye is in correct focus when the central point within this small range (corresponding to "yellow" light) is positioned on the retina). The test is used to assess the eye's focus by the observation of characters on a red and green background. The patient is asked to look at the chart and compare the letters on the red and green backgrounds. The practitioner may ask "On which side do the letters appear blacker and clearer? ...or do they appear equally black on both sides?" Thus, as shown in Figure 28

a) if the patients sees the characters more clearly on the red background, the central point of focus is anterior to the retina and so a minus lens is required to correct

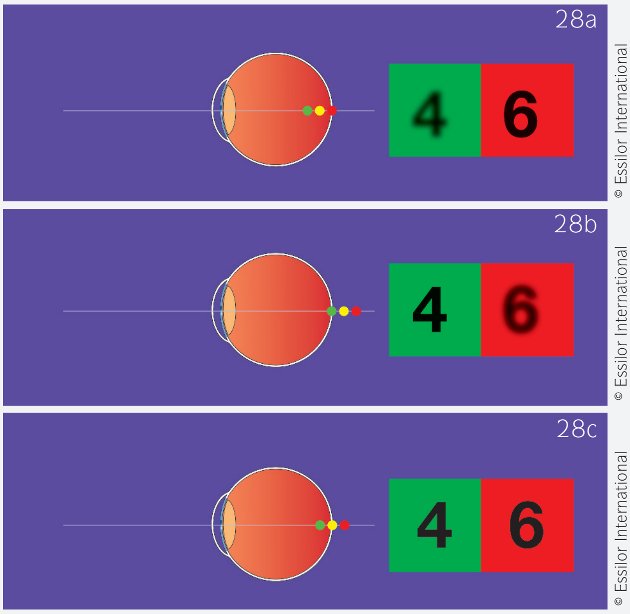


Figure 28: The Duochrome Test

the focus onto the retina (e.g. undercorrected myopia or overcorrected hypermetropia);

b) if the patient sees the characters more clearly on the green background, the central point of focus is posterior to the retina and so a plus lens is required (or the patient may accommodate) to correct the focus onto the retina (eg overcorrected myopia or undercorrected hypermetropia);

c) if the patient sees the characters as equally clear on the red and green backgrounds, the central point of focus is positioned on the retina and the patient is properly focussed for this test distance.

In order to prevent any unwanted effects of accommodation (which could lead to a preference for the characters on the red side), the practitioner may have the patient look at the green background before comparing it with the red, or the practitioner may fog by +0.50 D to obtain a preference for the red and then remove fog gradually until a balance between the red and the green sides is obtained.

Note that the Duochrome Test is equally applicable to those who have a colour vision deficiency; their altered perception of colours (light of different wavelengths) is independent from the chromatic aberration of the eye. In this case, simply ask the patient to indicate the side of the chart on which they see the letters more clearly, rather than specifying "the red side" or "the green side".

Note also that the chromatic aberration of the eye changes with the changes that occur within the refractive media of the eye with age; in particular, with the development of cataract. In this case, the Duochrome Test may be unreliable.

This test can be used for distance and near vision, in a monocular situation to check the sphere and in a binocular situation to balance the correction and for the final verification of the prescription.

At near it may be used to assess the accommodative behaviour of a young patient or to check the addition of a patient with presbyopia.

The Pinhole

The pinhole is a small hole (usually 1 – 2 mm in diameter) in the centre of a solid black disc. Its principal use during subjective refraction is that, in the case of reduced vision, it may enable differentiation of its cause, between refractive and pathological causes. For example, it may enable imprecise refraction to be distinguished from amblyopia ('lazy eye').

In practice, the pinhole is placed centrally in front of the patient's eye, over any correction already in place, and the vision is measured. If vision is improved with the pinhole, the cause of the reduced vision is a refractive one; for example an uncorrected, or ill-corrected, refractive error. If vision is not improved or becomes worse, the cause is not refractive in origin and amblyopia or other pathology should be suspected. In the absence of any pathology or opacity of the refractive media of the eye, the level of vision obtained with the pinhole should be able to be obtained by accurate refraction.

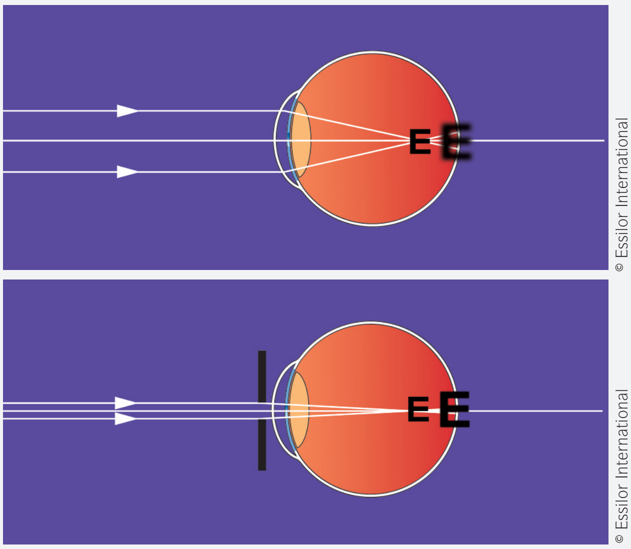


Figure 29: The Principle of the Pinhole

C Binocular Balance

Having determined the refractions of the right and left eyes separately under monocular conditions, it is important to ensure that these refractions correspond well under binocular conditions. This is the aim of binocular balance. The spherical component is adjusted as necessary to equalize the accommodative effort of the two eyes, so that the retinal images of both eyes may simultaneously be in focus. If this is not the case, asthenopia may result, as accommodation is destabilized.

Initially, the patient should be placed in (incomplete) binocular vision conditions in such a way that both eyes see separate views of the same test (simultaneous monocular vision). With each eye seeing the same image separately, the right and left eyes' vision can be compared and the best refractive balance found.

Various methods can be used to achieve such "simultaneous monocular" vision conditions. The two eyes are dissociated such that either (i) both eyes see the same target but never simultaneously, or (ii) each eye sees a different image of the same target and both are viewed simultaneously. The patient is then asked to compare the clarity of the two images. If one is seen more clearly than the other, plus lenses are added to the eye seeing the clearer image, until the two eyes see equally clearly. If there is never a point at which the patient sees equally clearly with both eyes, the dominant eye should be favoured and left slightly clearer.

Note that most binocular balance techniques can be performed only when the patient has equal visual acuity in both eyes; only certain techniques allow some binocular balance to be achieved when the visual acuities are unequal (for example, the doubled duochrome method).

Procedure:
1. dissociate the two eyes
2. add +0.50 D fog
3. have the patient indicate which eye sees more clearly
4. add plus lenses in front of this eye until the both eyes see equally (If both eyes never see equally, favour the dominant eye (leave it slightly clearer)).
5. Remove +0.50 D from both eyes.

1) Dissociate the two eyes by:

- **alternate occlusion**: this involves occluding first one eye then the other and rapidly continuing to alternate this occlusion such that the patient sees with both eyes but never simultaneously. During this test, the patient should never be placed in binocular vision conditions where both eyes see the target at the same time. In particular at the beginning of the test (that is at the end of monocular subjective refraction), occlude the eye that is open before uncovering the eye that is still closed.

- **vertical prism:** this involves placing a total of 6 base down right to dissociate the eyes, split between the eyes (3 BDR and 3 BUL) so the effect of the prism lenses on the quality of vision is equal for each eye. The introduction of this prism results in two images: the higher image is seen by the right eye, the lower by the left eye and thus the patient may compare the two images/eyes.

- **polarizing filters/lenses**: this method achieves dissociation by the use of polarized targets and polarizing lenses of mutually perpendicular orientations. Targets may include letters or polarized duochrome charts.

2) Fog binocularly by +0.50 D: Vision is reduced slightly and such blurred conditions enable the patient to make a comparison more easily.

3) Ask the patient to compare the images (which will be slightly blurred) seen by the right and left eyes and indicate which eye sees more clearly (image less blurred)

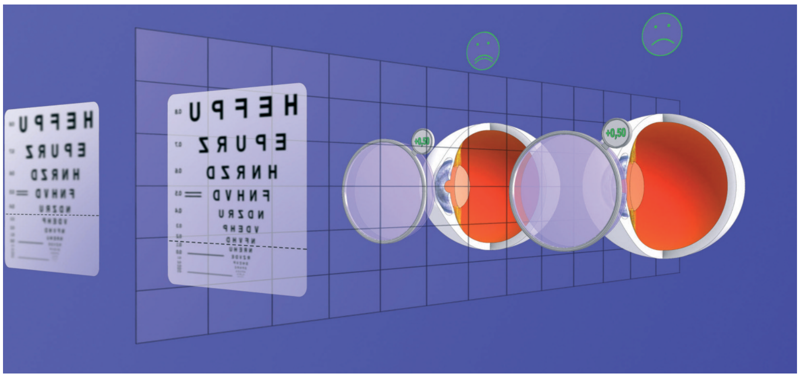
4) Equalise the vision (equalise the blur) of both eyes by further fogging the eye which sees more clearly (less blurred). Do this by adding plus lenses in +0.25 D steps until both eyes see equally. If both eyes never see equally, favour the dominant eye (leave it slightly clearer) so that the refractive correction respects the natural ocular dominance.

5) Remove +0.50D from both eyes, place the patient in full binocular vision conditions (both eyes open, viewing the same target) and check the level of vision, binocularly.

Note that binocular balance may be performed at both distance and near (see below).

Figure 30: Binocular Balance

a) + 0.50 D fog



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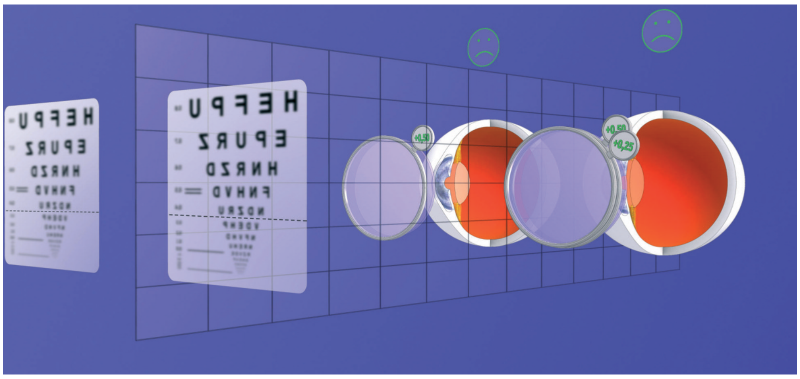
b) balance in the blur/fog



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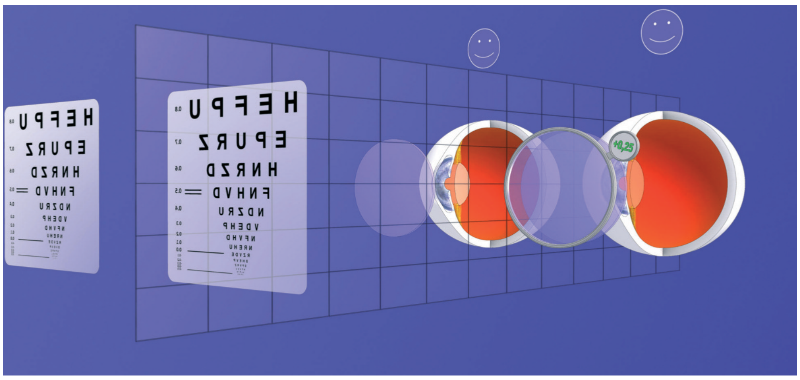
c) removal of fog binocularly



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D Final Check of Binocular Sphere, Subjective Appreciation and Comfort (including Binocular Vision Screening)

Finally, having determined the refraction of each eye separately and balanced one with the other, the sphere must be confirmed binocularly. The patient's binocular visual acuity may then be measured and furthermore their subjective appreciation of the final prescription judged.

Preferably, this final binocular verification of the sphere should be performed using a trial frame to allow more natural visual and spatial conditions than those achieved when the patient is positioned behind a phoropter.

Have the patient look at distance at some small detail. Present ±0.50D and ±0.25D binocularly over the existing correction and ask the patient to choose which lenses give the best vision. Record the binocular visual acuity.

Remember to take into account in the final prescription the fact that the subjective refraction has been performed at a finite distance and not at optical infinity. For this reason, when judging the final binocular sphere and comfort of the prescription, it is preferable to have the patient look outside, at the horizon. Indeed, the conventional test distance does not correspond to optical infinity. Subjective refraction performed using a chart at a distance of 6m gives rise to an error of 1/6m = 0.16D; 5m to an error of 1/5m = 0.20D. Although these errors are less than a prescribing increment of 0.25D, they are nonetheless potentially significant and may necessitate the adjustment of the final prescription by -0.25DS binocularly.

The binocular sphere may be checked as follows:

1) Place the subjective refraction result in the trial frame and have the patient focus as far away as possible (for example, on the horizon), looking with both eyes open.

2) Place an extra +0.25 D in front of both eyes (using a binocular lens holder) and ask the patient if this makes their vision 'better, worse or no different'.

a. If vision is worse, the refraction result in the trial frame is correct or over-plussed. Do not add the extra +0.25D to the refraction result. Go on to step 3).

b. If there is no change, the refraction result in the trial frame is over-minussed or under-plussed; add the +0.25 D binocularly to the refraction result and repeat step 2).

c. If vision is better, the refraction result in the trial frame is (even further) over-minussed or under-plussed; add +0.25 D and repeat step 2). If > +0.50 needs to be added, redo the refraction.

3) Now, in the same manner, place -0.25 D in front of both eyes.

a. **If vision is worse**, the refraction result in the trial frame is now correct. This is the final refraction.

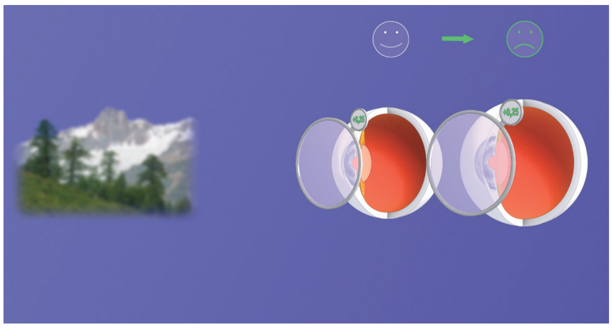
b. **If there is no change**, the refraction result in the trial frame is correct or slightly over-minussed. Make a judgment whether or not to add the extra -0.25D.

c. **If vision is better**, the refraction is over-plussed or under-minussed: add -0.25 D and repeat step 3). If >-0.50 needs to be added, redo the refraction.

In summary, the response sought during binocular verification of the sphere correction is a reduction of clarity and comfort with an extra +0.25 D and an absence of real change observed with an extra -0.25 D. The value of the sphere in the patient's refraction should be adjusted binocularly in order to obtain this result.

Figure 31: Binocular Check of the Sphere, Subjective Appreciation and Comfort

a) with +0.25D – vision is blurred



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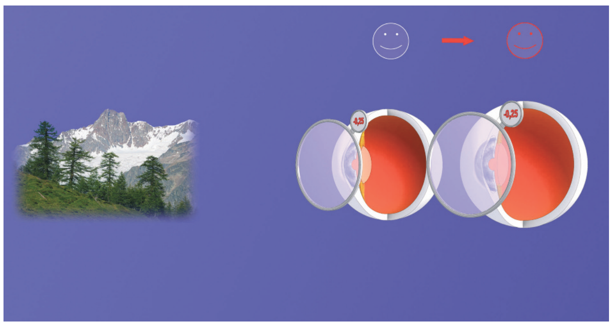
b) with -0.25D – vision is unchanged



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Binocular Vision Screening

At this stage of the examination, it is important to check the patient's binocular vision; more precisely, it is important to confirm that the patient has good simultaneous vision and that the images perceived by both eyes are *fused* without difficulty. To evaluate this, the patient's binocular vision must be dissociated in order to check that:

1) there is not total or partial suppression of the vision in one eye, by ensuring the **permanent presence of two images**

2) there is not potential deviation or significant phoria, by checking the **alignment of the two images.**

Note that simultaneous vision may already have been observed during the binocular balance test.

Depending on whether binocular vision is dissociated by means of prisms, red-green filters or polarized filters, for example, one of the following tests could be carried out:

Dissociation by prisms (Von Graefe method)
Its principle is to dissociate binocular vision by means of vertical prism. The patient looks at a line of letters, first vertical then horizontal. Proceed as follows:

a) Place a 6 base down prism in front of the right eye (or 3 BDR and 3 BUL).

b) Check that the patient sees two images simultaneously, one high (the right), the other low (the left) (the image is moved towards the prism's apex). If only one image is seen, one eye is suppressed.

c) Have the patient assess the horizontal separation of the two vertical lines (or measure by means of prisms)

a. If the two lines are aligned, there is orthophoria.

b. If the two lines are offset, there is (horizontal) heterophoria. (Combined horizontal and vertical phoria, or cyclophoria, may also be revealed with this test).

d) Now perform the test by dissociating the eyes by using a horizontal prism of 10 to 15 base in over one eye and by having the patient look at a horizontal line of letters; two images should be seen separated horizontally; any vertical heterophoria may be demonstrated and measured.

Remember that for all dissociation tests:

- If the image seen by the right eye is to the right and the image seen by the left eye is to the left, there is esophoria.

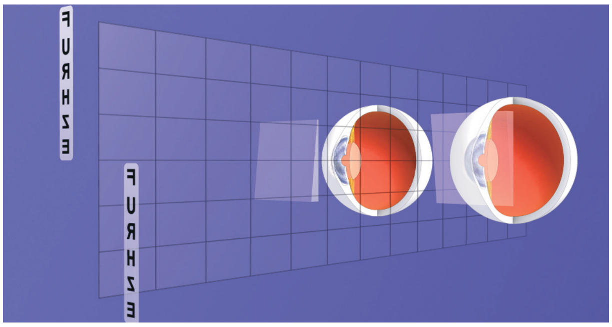
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Figure 32: Dissociation by Prisms

- Conversely, if the image seen by the right eye is to the left and the image seen by the left eye is to the right, there is exophoria.

- Most people have some degree of heterophoria. This poses a problem only if compensation for it proves difficult, for example.

Dissociation by coloured filters (Schober test):
This test is comprised of a red cross and 2 green circles seen through red and green filters by the right and left eyes. The eye fitted with the red filter sees the red cross; the eye fitted with the green filter sees the green circles. Proceed as follows:

a) Place a red filter over one eye and a green filter over the other.

b) Ask the patient what they see:

a. If both the cross and the circles are seen, there is simultaneous vision.

b. If only the cross or only the circles are seen, there is suppression in one eye.

c) Ask the subject to identify the location of the cross relative to the circles:

a. If the cross is seen in the centre of the circles, there is orthophoria.

b. If the cross is seen as off-centre, there is heterophoria.

Normally the patient should see both the red cross and the green circles. The cross should lie within the green circles.

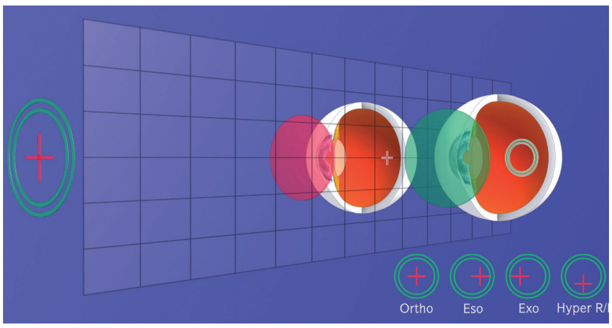

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Figure 33: The Schober Test

Dissociation by polarized tests (Polarized Cross Test): The polarized cross is available in the majority of projectors charts. Proceed as follows:
On procède comme suit :

a) Place the polarized filters in front of both eyes.

b) Ask the patient if both branches of the cross are clearly visible:

a. If the full cross is clearly visible, there is simultaneous vision.

b. If only one branch is visible (or one branch tends to disappear and re-appear), there is (full or intermittent) suppression of one eye.

c) Ask the patient if both branches of the cross are perfectly centred or if one of them seems offset relative to the other:

a. If the branches are centred, there is orthophoria.

b. If they are offset, horizontally and/or vertically, there is heterophoria.

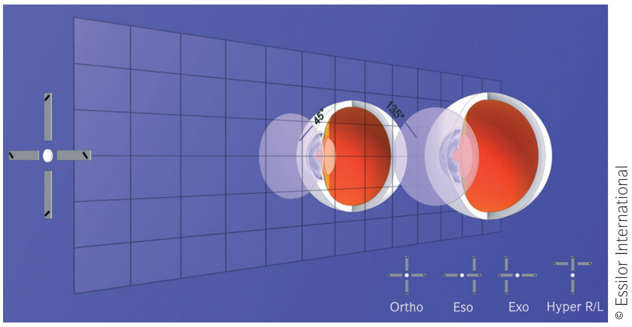

Figure 34: Polarized Cross Test

Stereopsis
To assess the subject's stereoscopic vision, use a test that enables two separate images to be presented to the subject. These images are almost identical but slightly offset relative to one other so that they create a perception of relief (that is, three dimensional vision) when they merge. These tests achieve dissociation by means of red and green filters (Brock technique) or polarized filters (for example, polarized rack test). They involve checking that a part of the image is perceived by the patient as being closer or further than the rest of the image. The principle is that when the two eyes fuse, if the image seen by the right eye is slightly offset to the right and that seen by the left eye is slightly offset to the left, the patient has the impression that the plane of the test recedes; conversely, if the image seen by the right eye is slightly offset to the left and that seen by the left eye is slightly offset to the right, the patient has the impression that the plane of the test advances. The presence of even a slight degree of stereoscopy implies a very good level of binocular vision.

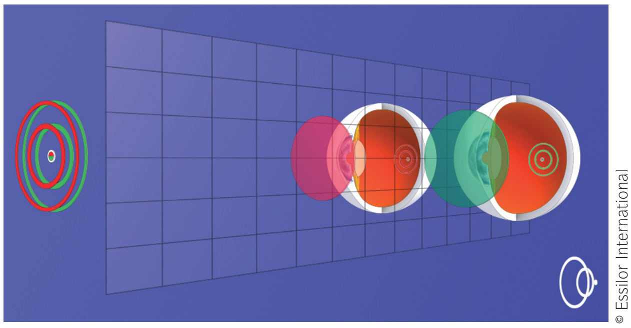

Figure 35: Brock Rings Test

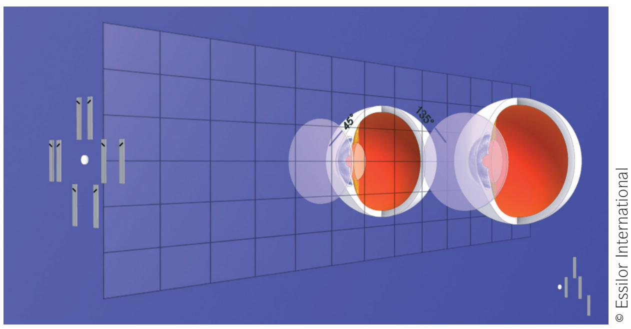

Figure 36: Polarized Bar Test

If a binocular vision anomaly is detected, proceed to a more detailed evaluation such as that described below in the Chapter 'Binocular Vision Evaluation'.

5. Subjective Refraction Near Vision

A Determining the Near Addition (Presbyopia)

Precise determination of their appropriate near addition is vital for the comfort of the presbyopic patient. As with distance vision ametropia, the patient's presbyopia should be measured and the near addition determined from the measurement of the maximum remaining accommodation amplitude; this is because, at any given age, the remaining amplitude of accommodation will differ between patients.

1) ACCOMMODATIVE RESERVE METHOD

The method involves determining the subject's maximum remaining amplitude of accommodation and subsequently calculating the value of the addition to be prescribed. The procedure is performed in binocular vision conditions, with the distance vision correction in place, using a reading test which may be at a fixed or variable position.

a) Measure the remaining amplitude of accommodation:

Using a reading test which can be moved, find the position of the near point of accommodation by moving the text towards the patient until it (just) becomes blurry (that is, find the closest point to which the patient can focus at near). The amplitude of accommodation is the inverse of this distance: for example, if the distance is 0.50 m, the amplitude of accommodation is 1/0.50m = 2.00 D.

Using a reading test at a fixed position:

- **Place the test at 40 cm** (1/0.40m = 2.50D) and ask the patient to focus on the smallest characters possible.
- **If the smallest text is clear, introduce lenses of -0.25 D, -0.50 D, etc,** until the patient is no longer able to see the text clearly.
- **If the smallest text is blurry, introduce lenses of +0.25 D, +0.50 D, etc,** until the patient can (just) see the text clearly.

Amplitude of Accommodation = 2.50 D – power added.

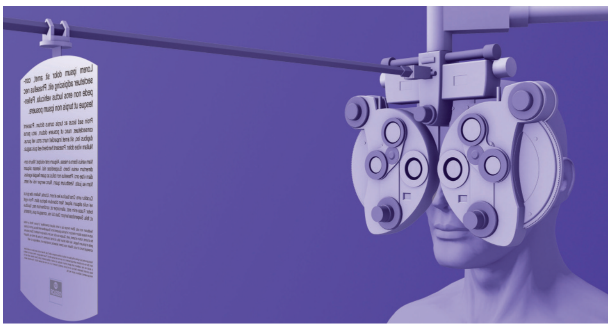

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Figure 37: Measuring the Amplitude of Accommodation in the Presbyopic Patient

b) Determine the addition:

A patient may use comfortably for a sustained period only 2/3 of their amplitude of accommodation (thus keeping an accommodative reserve of at least 1/3 of the amplitude of accommodation).

Thus the near addition is given by the formula:

Near addition = 1 / reading distance – 2/3 maximum amplitude of accommodation

Near addition values for respective reading distances of 40 cm, 33 cm and 25 cm, are given in the table below:

Remaining Amplitude of Accommodation	Comfortable Accommodation (Percival criterion) (= ou <2/3 acc max)	Addition for 50 cm (=2.00D-2/3acc)	Addition for 40 cm (=2.50D-2/3acc)	Addition for 33 cm (=3.00D-2/3acc)	Addition for 25 cm (=4.00D-2/3acc)
3.00	2.00	No add	0.50	1.00	2.00
2.75	1.83 / 1.75	No add	0.75	1.25	2.25
2.50	1.66 / 1.50	0.50	1.00	1.50	2.50
2.25	1.50	0.50	1.00	1.50	2.50
2.00	1.33 / 1.25	0.75	1.25	1.75	2.75
1.75	1.16 / 1.00	1.00	1.50	2.00	3.00
1.50	1.00	1.00	1.50	2.00	3.00
1.25	0.83 / 0.75	1.25	1.75	2.25	3.25
1.00	0.66 /0.50	1.50	2.00	2.50	3.50
0.75	0.50	1.50	2.00	2.50	3.50
0.50	0.33 / 0.25	1.75	2.25	2.75	3.75

c) Check the patient's visual comfort

- Have the patient try the distance vision correction and the near addition (trial frame)
- Ask the patient to assess near vision comfort by a reading test
- Ensure the value of the addition is in accordance with the patient's required reading/working distance and any other visual needs; adjust if necessary.

2) MINIMUM ADDITION METHOD

This method involves restoring to the presbyopic patient an apparent “accommodation” of 3.50 D (that is, the “accommodation” necessary for the usual near activities of daily living) by bringing their corrected near point to a distance of 28 cm (= 1 / 3.50 D). To do this, determine the minimum addition necessary for the patient to read at 40 cm (proximity 2.50 D) and then add +0.75 D to +1.00 D to attain 28 cm (proximity 3.50 D).

a) Correct distance vision precisely

Remember to correct the ametropia at the level of maximum plus for maximum visual acuity. This is important because any under-correction of hypermetropia or over-correction of myopia may translate into an excessive addition for near vision and this is best avoided.

b) Determine the minimum addition at 40 cm

Place a reading test at 40 cm and ask the patient to focus on the smallest characters. If the patient is presbyopic, the smallest characters will be blurry. Add +0.25 D, +0.50 D, etc, binocularly to the distance vision correction until the subject can just make out the smallest characters on the test. The value of the lenses added is the *minimum addition.*

c) Add +0.75 D or +1.00 D to the *minimum addition* to find the *comfortable addition.*

d) Check the patient's visual comfort

Using trial frames and a reading test:

- ask the patient to assess their visual comfort with the addition in place
- bring the test closer to the patient until the smallest characters are no longer able to be seen clearly. This should occur at approximately 25 cm from the eyes (if <20 cm, the addition is too strong, if >30 cm the addition too weak).
- adjust the value of the addition (from 0.25 to 0.50 D) in accordance with the required working or reading distance, if different from the 40 cm at which the test was conducted. Reduce the addition for a longer working distance, increase it for a shorter working distance

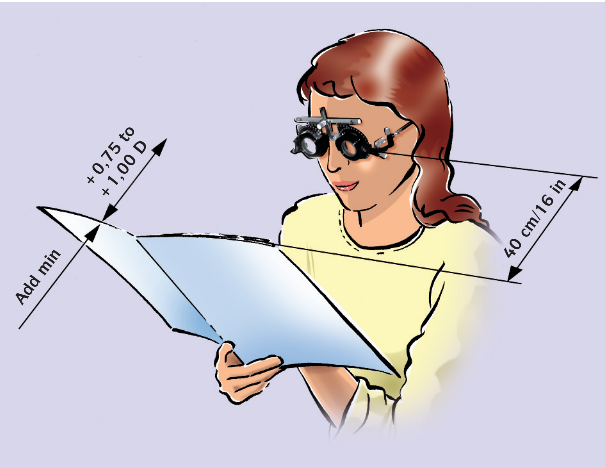


Figure 38: Principle of the Minimum Addition Method

3) BINOCULAR FIXED CROSS CYLINDER METHOD

This procedure involves determining the presbyopic near addition by introducing a ±0.50 cross cylinder (prescription +0.50/-1.00x90) in front of both eyes and having the patient look at a cross, made up of horizontal and vertical lines, at a distance of 40 cm. As the presbyopic patient has insufficient accommodation, and given the orientation of the cross cylinders, the horizontal lines of the cross are seen more clearly than the vertical lines, initially. Plus lenses are then introduced binocularly, progressively in 0.25D steps, until the horizontal and vertical lines of the cross are seen equally clearly; the plus in place at this point is the near addition for 40cm. In practice, perform the following steps (most simply using a phoropter, as the binocular fixed cross cylinders are integrated therein):

a) Correct distance vision precisely
Remember to prescribe maximum plus for maximum visual acuity.

b) Determine the addition:
- Have the patient fixate on a cross composed of horizontal and vertical lines, placed at 40 cm.
- Introduce the ±0.50 cross cylinder (negative axis along 90°) in front of both eyes. The patient now sees the horizontal lines of the cross more clearly.
- Introduce binocularly lenses of +0.25, +0.50, +0.75 D, etc, progressively until the patient sees the horizontal and vertical lines as equally black and focussed.
- Continue until the patient sees the vertical lines more clearly.
- Select as the addition the value that gives the best equality between horizontal and vertical lines.

c) Check the patient's reading comfort:
- Place into a trial frame the distance vision correction and the addition obtained
- Ask the patient to assess their visual comfort via a reading test
- Adjust the value of the addition in accordance with the patient's required working or reading distance.

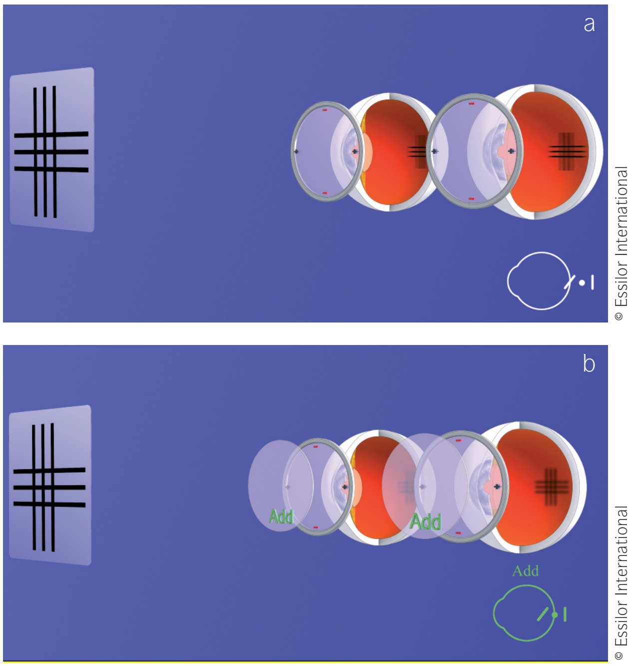


Figure 39: Binocular Fixed Cross Cylinder Test

The Consequences of Prescribing an Excessive Near Addition

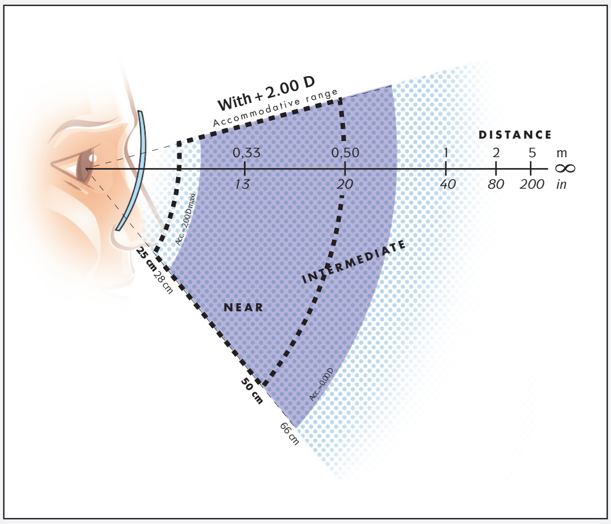
The amount of addition prescribed directly influences the corrected presbyopic patient's range of vision. Indeed, the limits of the range of near vision are determined by the power of the addition and the remaining amplitude of accommodation. The near vision accommodation range becomes closer and more restricted as the addition becomes stronger, and also becomes more restricted as the remaining amplitude of accommodation becomes smaller. Thus:

- a stronger addition reduces the apparent depth of the usable range of accommodation.
- as presbyopia progresses, the increase in addition and the reduction in the remaining amplitude of accommodation combine to reduce the depth of the usable range of near vision.

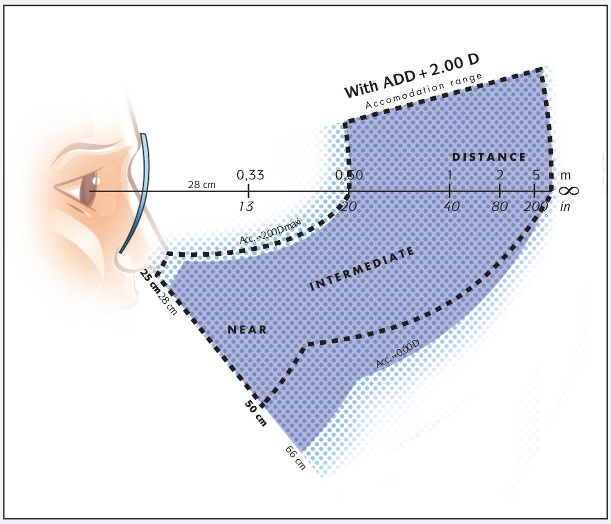
As an example, consider a young presbyopic patient corrected by a single vision near lens of power +1.50 D (Figure 40a) or a progressive lens of addition +1.50 D (Figure 40b). In accordance with the *minimum addition* method detailed previously, the patient's remaining (maximum) amplitude of accommodation is 2.00 D. A very simplified theoretical calculation shows that this range of accommodation extends in distance vision from infinity to 50 cm and in near vision from 67 cm to 28 cm. If an addition of +2.00 D were prescribed instead of +1.50 D, the range of near vision is modified and then extends between 50 cm and 25 cm. Thus, over-correcting the addition by +0.50 D has the consequence of reducing the range of clear vision by 17 cm in the distance zone (from 67cm to 50cm) and procures a gain of only 3 cm at near (from 28 to 25cm). The consequence is that the patient has a more restricted range of clear vision.

Figure 40 : Depth of Field of Clear Vision in an Early Presbyope:

a) Single vision lens of power +1.50 D



b) Progressive lens of addition +1.50 D



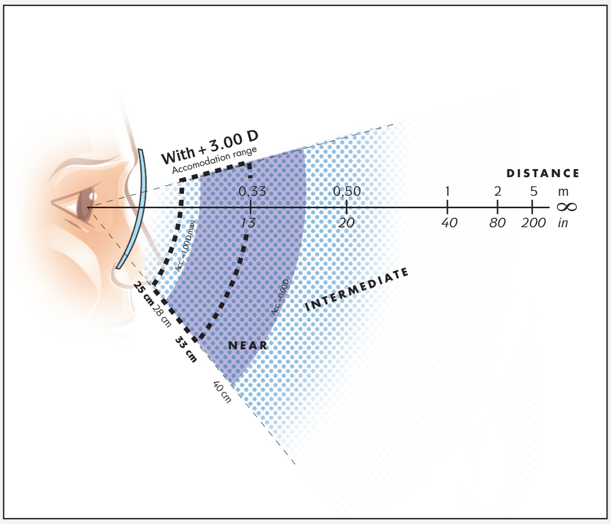
A few years later this patient will have a remaining amplitude of accommodation of only 1.00 D and thus require, still in accordance with the *minimum addition method*, an addition of +2.50 D (Figure 41). Their near vision accommodation range has naturally diminished and now extends from 40 cm to 28 cm. If the addition is over-corrected by +0.50 D (by prescribing an addition of +3.00 D instead of +2.50 D), the range of clear vision extends from 33 cm to 25 cm, so there is a loss and restriction of 7 cm in the depth of field for intermediate vision for a gain of only 3 cm in very near vision.

In progressive lenses, increasing the addition reduces the field of vision not only in depth, but also in width. Prescribing an excessive near addition increases the lateral aberrations of the lens, thus reducing the usable width of the central zone and increasing the effect of peripheral deformations. Excessive near additions are a major cause of difficulty in adaptation to progressive lenses.

During the determination of the addition, most presbyopic patients naturally demand greater plus power because of its associated magnifying effect. However, an increase of +0.50 D in a near prescription, apparently comfortable and safe during refraction, can prove uncomfortable on a day-to-day basis. This is a reason why any near prescription should be trialled by the patient in natural conditions, and the clear range of vision checked, prior to prescribing. The art of prescribing for near lies in knowing how to use the addition with moderation and to gauge precisely the correction of presbyopia.

Figure 41 : Depth of Field of Clear Vision in a Late Presbyope

a) Single vision lens of power +2.50 D



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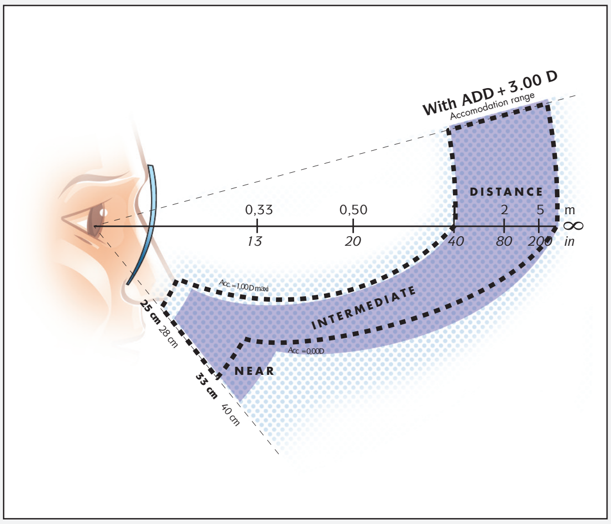
b) Progressive lens of addition +2.50 D



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B Verification of Binocular Balance at Near

Once the distance refraction and near addition have been determined, the patient's binocular balance should be checked at near, also. Indeed, binocular balance has been established in distance vision in a situation that is seldom encountered: looking at far distance in primary gaze (straight ahead, at eye level). In near vision, a lowered line of gaze and the stimulation of accommodation and convergence may modify that balance. This should be checked by dissociating binocular vision at near with the eyes lowered. This may be performed with instruments such as the *Optoprox®* or the *Proximeter®*. The principle is as follows:

1) Dissociate the patient's binocular vision at near:

Place the patient's near correction in the trial frame. Position the test at a set distance (for example, 40 cm) and check that the patient's line of gaze is lowered. Dissociate their binocular vision:

a. by means of polarizing or red-green filters (Optoprox®)

b. by means of the septum (Proximeter®)

The patient is now in a situation of incomplete binocular vision which enables the vision of the two eyes to be compared.

2) Have the subject compare the vision of the right and left eyes and determine balance:

a. If there is equality of vision between the right eye and left eye, balance is achieved.

b. If there is a difference in vision between the two eyes, balance by introducing +0.25DS on the worse eye or -0.25DS on the better eye. Usually no more than 0.50 D adjustment is necessary.

Remember that this balance pre-supposes visual acuity that is essentially equal in both eyes. Note also that it is necessary to know which is the patient's dominant eye and that a slight imbalance in favour of that eye may be conserved. More precisely, be careful never to reverse the natural dominance of one eye relative to the other.

3) Assess acceptance of the near vision balance at distance:

If the near vision balance differs from the distance vision balance, in general it is preferable to favour the near balance and check that it is acceptable at distance. To do this, introduce the balance lens (usually +0.25 to +0.50 D) over one of the eyes in front of the patient's distance correction. If the patient indicates no discomfort, keep that balance. Otherwise, two sets of lenses may need to be prescribed: one for distance vision, the other for near vision.

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Figure 42: Optoprox®

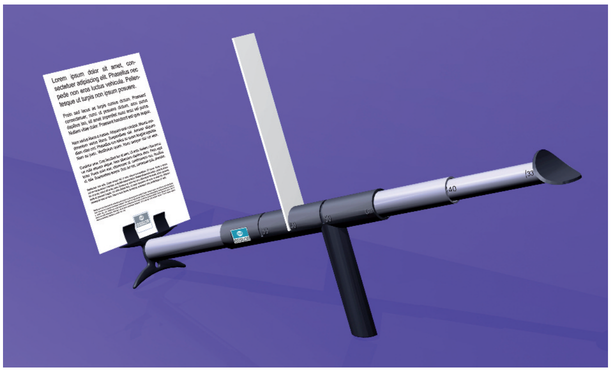

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Figure 43: Checking Binocular Balance at Near using the Proximeter®

Checking the binocular balance at near is particularly important in presbyopic patients who, due to loss of accommodation, are very sensitive to the simultaneous action of both eyes in close vision.

C In the case of the Non-Presbyopic Patient

For non-presbyopic patients, the near vision examination is often carried out only if the patient has symptoms or expresses a visual complaint, or if an anomaly has been discovered during the preliminary measurements; however, it should be performed in all cases, as many anomalies may not cause significant symptoms. Usually, symptoms involve visual fatigue (asthenopia) after periods of close work. This tiredness can have various origins which may be normal (that is, some fatigue is expected even when the eyes and visual system are entirely normal) or abnormal and, in particular, may be caused by a uncorrected ametropia, a binocular vision disorder or accommodative fatigue.

1) Uncorrected Ametropia

Usually patients will suffer symptoms of visual fatigue at near in the case of uncorrected hypermetropia or at distance in the case of uncorrected astigmatism. Uncorrected hypermetropia demands permanent accommodative effort, which is tiring in the long term. Uncorrected astigmatism destabilizes accommodation and requires an effort of compensation, which can be a source of headaches. The solution consists essentially in ensuring effective correction of distance vision and checking that this provides relief to the patient in near vision, also.

A particular case is that of the pre-presbyopic patient who, by this stage, has often been starting to be unable to compensate for latent hypermetropia for some time. Latent hypermetropia may develop more rapidly than early presbyopia. Be sure not to confuse hypermetropia and presbyopia and to correct distance vision fully. Often, the patient wears this correction only at near, initially, then progressively adopts it for distance vision.

2) Binocular Vision Disorder

Two of the most common disorders which may be encountered are *convergence insufficiency* and difficulty in compensating for severe heterophoria.

- convergence insufficiency will be detected during the preliminary measurements. It may be treated primarily by visual training and exercises and, if this fails to prove effective, possibly by prismatic correction.
- severe heterophoria may be accentuated by down gaze (that is, a lowered line of gaze such as during near vision). It may be identified at near by the unilateral cover test, sometimes more easily than at distance. For further discussion, see the Chapter 'Binocular Vision Evaluation'.

3) Accommodative Fatigue

This is manifested as a difficulty in maintaining focus during near vision. The patient may suffer tiredness and blurred vision after periods of near work. For example, this condition is often encountered in students who have a large near demand and so accommodate strongly over sustained periods of time. To help identify the exact nature of the problem, the two following measurements may be made:

- **amplitude of accommodation** (by the fixed test method described previously for presbyopes): a reading test is positioned at near, in natural down gaze, at 40 cm for example. Minus lenses are introduced progressively (in steps of -0.25 to -0.50 D) until the patient can no longer see the small characters clearly. The value at which the characters are still just able to be cleared by the patient is used to calculate the amplitude of accommodation: amplitude of accommodation = 1/0.40 m – added power. This measurement is then compared to statistical norms. The amplitude of accommodation often proves to be lower than the average in such cases.
- **accommodative facility** (may be measured using the *accommodative rock* method): wearing the distance correction, have the patient fixate on a small word placed at 40 cm. Using a flipper (binocular lens holder) fitted with +2.00 D and -2.00 D lenses, assess the number of accommodation/disaccommodation cycles that the patient can perform in one minute. To do this, firstly place the +2.00 D lenses (to relax accommodation) and ask the patient to indicate as soon as the word is clear. At this point, immediately swap the lenses so that now the -2.00 D lenses are in place (to stimulate accommodation) and ask the patient to indicate when the word is again clear. Repeat this cycle for 1 minute and count the number of cycles executed: generally it is considered that ~13 or more cycles is normal, ~8 or fewer cycles abnormal. If the patient is unable to clear ±2.00D, ±1.00D flippers may be used instead, although this already gives an indication of reduced accommodative amplitude and facility. (*Accommodative infacility* may often be associated with *accommodative insufficiency* and *convergence excess* and so it should not be measured in isolation).

If accommodative insufficiency and/or reduced accommodative facility is observed, this may sometimes be treated by vision therapy and eye exercises or by the prescription of a weak plus correction in near vision, on condition that there are no binocular counter-indications. For this reason these results should not be taken in isolation and a full binocular vision assessment should be performed by an appropriately qualified eye care professional.

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Figure 44: *Accommodative Rock* Test

6. Binocular Vision Evaluation

If a binocular vision anomaly is detected through screening, it is necessary to proceed to a more in-depth examination in order to identify and treat the problem. This should be performed only by an appropriately qualified eye care professional, with referral if necessary.

The object of this chapter is not to provide a full description of the investigation and treatment of binocular vision disorders; this is a vast subject and beyond the scope of this file. Rather, it is simply to recall a few basic principles, to describe how to identify some binocular vision disorders and to offer some tips for prescribing a prismatic correction.

A Phoria, Fusional Reserves and Tropia

Definitions

1) Phoria:

Heterophoria, often simply called *phoria*, can be defined as a 'latent deviation of the visual axes compensated by the stimulus to maintain fusion and avoid diplopia', or stated another way, the 'tendency for the two visual axes of the eyes not to be directed towards the point of fixation, in the absence of an adequate stimulus to fusion'. The eyes make a permanent effort of compensation for any phoria so as to maintain the visual axes of both eyes on the point of fixation.

Phoria can be demonstrated by dissociating binocular vision in order to inhibit fusion. This dissociation can be either **sensorial** by disrupting the similarity of the images (dissociation by filters, for example) or **motor** by disrupting their superimposition (dissociation by prisms, for example). Depending on the test chosen, the dissociation can also be shallow or deep, central and/or peripheral, partial or total.

Depending on the measurement conditions, that is, depending on the type of dissociation selected, the phoria will be said to be '**associated**' or '**dissociated**'. When the test used involves an element of fusion, perceived in common by both eyes, the phoria is said to be 'associated' (the red filter test, Mallett test, etc.). When no element of fusion is present, the phoria is said to be 'dissociated' (dissociation by prisms, Maddox test, etc.).

Typical values for dissociated horizontal phoria are generally considered to be ~0.5 exophoria at distance and 4 - 6 exophoria at near; for dissociated vertical phoria, ~orthophoria (0) at both distance and near.

2) Fusional (Vergence) Reserves:

The eyes naturally possess vergence reserves or fusion latitudes, indicative of the ability of the visual system to maintain fusion and compensate for any heterophoria. Fusional reserves are the tolerance of the eyes to converge or diverge relative to a given fixation point or indeed their capacity to resist any prismatic disturbance of their fusion. When assessing the reserves, three particular points or stages should be noted:

- the point at which further relative vergence induces accommodation; this point is marked by first blurring of the fixation target (this point is the *blur* point);
- the point at which fusion is disrupted and where the images of the two eyes separate; this is usually marked by doubling of the image, or diplopia (*break* point);
- the point at which fusion of the two eyes is recovered; this is usually marked by a return to a single image (*recovery* point).

Typical values of fusional reserves (the *blur/break/recovery* points) are shown in Figure 45. In distance vision, they are approximately twice as large in convergence as in divergence. In near vision, they are noticeably more balanced between convergence and divergence. In the vertical plane, fusional reserves are low.

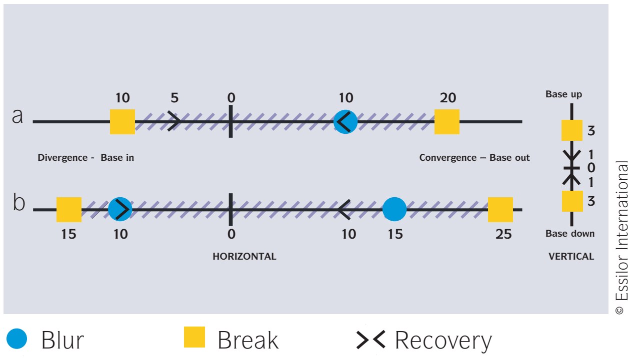


Figure 45: Typical Values of Phoria and Fusional Reserves
a) at distance
b) at near

To assess a patient's fusional reserves, the practitioner can either screen for fusional capacity or measure the convergence (also called *positive relative convergence*) and divergence reserves (*negative relative convergence*). The principle is to introduce prisms of different amounts and check at each stage that the patient can compensate for their effect at a given fixation and accommodation point. To induce convergence, introduce a base out prism; to induce divergence, use a base in prism. Always induce and measure divergence ability before testing convergence.

a) Screening for fusional reserves: this involves checking the capacity of the eyes to compensate for the introduction of prisms of known values; in distance vision, 5 base in and 10 base out; in near vision, 10 base in and 10 base out. In practice, ask the patient to look at, for example, a vertical line of letters, and place the prism in front of one of the patient's eyes. The image should initially be seen as double, then single as the patient fuses. If this is not so and two images are still perceived even after several seconds then fusional reserves are low.

b) Measuring fusional reserves: this involves using a prism bar or prisms in the phoropter, to introduce prisms of increasing power in order to find the blur, break and recovery points. To measure horizontal reserves (divergence first, then convergence), have the patient look at a vertical line of small letters appropriate for their level of vision. Introduce the prism, progressively increasing its power, until blurring occurs. (At this stage, convergence will have caused the stimulation of accommodation. Also, do not be concerned if the patient does not notice the blur; some do not). Note the power of prism at this blur point. Continue until one eye loses fixation and/or the patient sees double (that is, fusion breaks and the eyes can no longer compensate for the prism). Note the power of prism at this break point. Then reduce the value of the prism until fusion is recovered (*recovery*). Proceed in a similar way for the vertical reserves, but rather with the patient looking at a horizontal line of letters, and using much lower prism values.

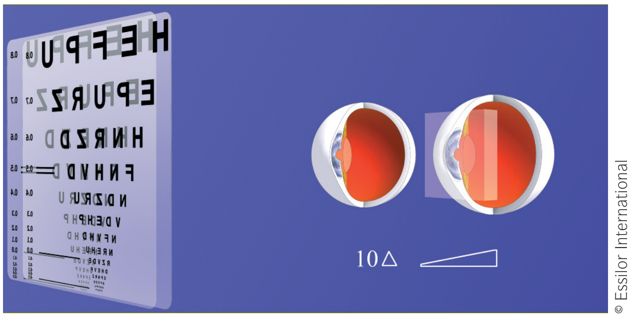
(Vergence facility may be measured, also; this is not treated here.)

3) Tropia (or strabismus):

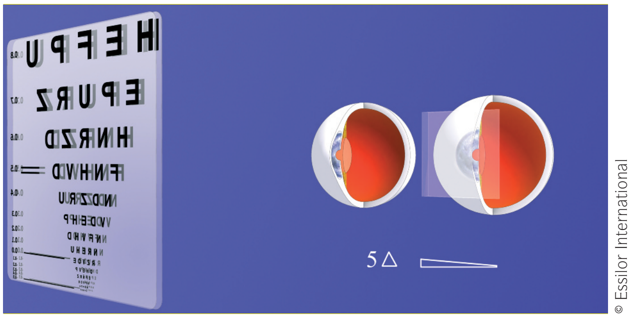
The fundamental difference between (hetero)phoria and (hetero)tropia is that bifoveal fixation is maintained in phoria but is not in tropia; in tropia, one eye is turned such that its visual axis does not coincide

Figure 46 : Screening Fusional Reserves

a) convergence



b) divergence



with the fixation target or object viewed by the patient and so its image does not fall on the fovea of the tropic eye. Tropia may result from many causes (refractive, anatomical, neurological or pathological) and may be constant or intermittent, comitant or incomitant, unilateral or alternating, accommodative or non-accommodative, for example.

One cause may be the decompensation of a phoria. When the eyes can no longer compensate for phoria, the turned eye's deviation becomes marked in ordinary conditions of vision and may even become continuous. The visual axis of one eye no longer passes through the fixation point and it is at this point that the phoria breaks down to a tropia: *exotropia* if the eye diverges, *esotropia* if it converges, *hypertropia* if it turns up or *hypotropia* if it turns down. It may be accompanied by *diplopia* (recognition of double vision, that is the two different images from the two eyes) but instead is often accompanied by cortical suppression of the vision of the turned eye. Diagnosis and treatment of tropia is complex and requires the competence of a specialist in binocular vision. The object of this chapter is not to discuss these questions in detail but only to describe and identify some examples of the condition.

B Identifying the Problem

When a binocular vision anomaly is detected during initial screening or during the binocular verification of the refraction, the nature of the problem must be identified. More precisely, it is vital to establish whether the anomaly is related to a poorly compensated phoria or a tropia. In either case, the condition must be measured and analyzed.

1) Differentiating phoria from tropia:

Phoria and tropia may be differentiated by the *unilateral* and *alternating cover tests*. Already mentioned among the preliminary tests, this involves observing the movement of the eyes during the occlusion and uncovering of one eye then the other, while the patient focuses on a target at distance or near.

(Please note:
- the examples given below include only some types of phoria and tropia.
- some very small phorias and tropias may be missed via observation with the naked eye.
- the size of the deviation may vary depending on the speed at which the cover test is performed (that is, the duration of occlusion and the speed of cover/uncover)).

a) Demonstrating tropia (using the unilateral cover test):

- Have the patient focus on a target.
- Occlude the right eye while observing the left eye:
- If no movement is observed, the left eye was fixating and was not deviated.
- If a movement of refixation is observed, that eye was deviated:
  - if the refixation movement is towards the nose (that is the eye was turned out) – exotropia; if the movement is towards the temple – esotropia
  - if the movement is downwards – hypertropia; if upwards – hypotropia
- Remove the occluder from the right eye.
- Repeat the procedure, occluding the left eye and observing the right eye.
- If a movement is observed in one eye or the other, tropia is identified, the test is complete.
- If no movement is observed, proceed to search for phoria (step b), below).

b) Demonstrating phoria (using the unilateral cover test) (*continued on from demonstrating tropia, above, if no tropia were demonstrated)*:

- Have the patient focus on a small target
- Occlude the right eye for 1 to 2 seconds
- Quickly uncover while observing the right eye as it is uncovered:
- If no movement is observed, there is orthophoria or low-level heterophoria.
- If a refixation movement is observed, there is heterophoria:
  - exophoria, if the movement is towards the nose; esophoria, if the movement is towards the temple.
  - hyperphoria if the movement is downwards, hypophoria if upwards.
- Repeat the procedure, occluding the left eye and confirm the behaviour observed in the right eye.
- If a movement is observed in one eye or the other, phoria of at least a moderate amplitude is identified.
- If no movement is observed, there is orthophoria or low-level heterophoria (less then 2 to 3).

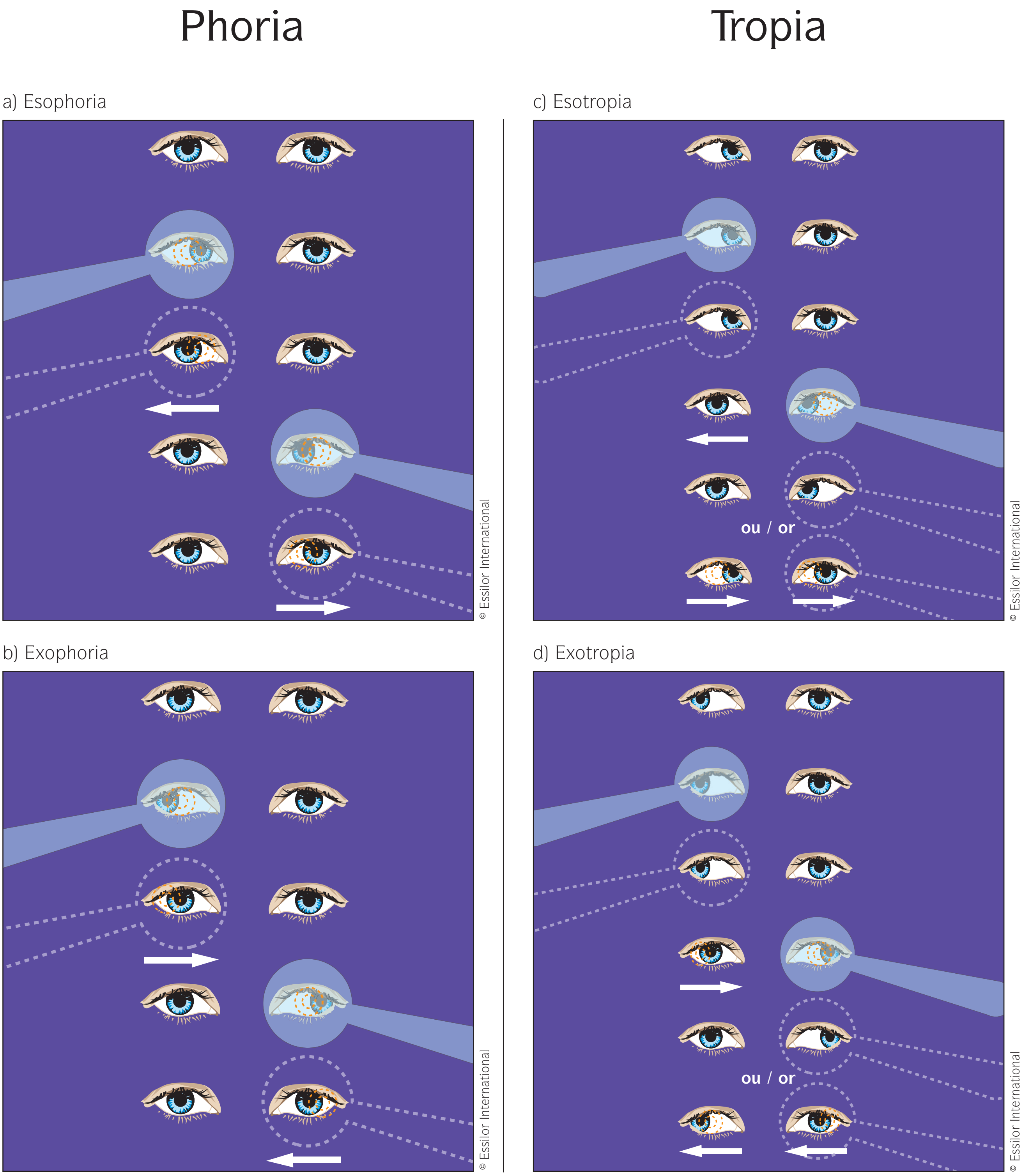


Figure 47: Demonstrating Tropia and Phoria using the Unilateral Cover Test

2) Measuring and analyzing phoria:

Once the existence of phoria is identified, its impact must be measured and the patient's capacity for its compensation must be assessed. This should be done at both distance and near.

a) Measuring phoria and fusion amplitudes
From the many possible methods of measuring phoria, the method using the alternating cover test, a trial frame and a prism bar is outlined below. This has the advantage of measuring phoria in spatial vision conditions, in which some fusion is maintained. It may also be used where subjective input is impossible, although it relies on observation with the naked eye and so small phorias may be missed. Measurement is carried out as follows, with the refractive correction in place:

- Have the patient focus on a target.
- Occlude one eye for 2 to 3 seconds.
- Quickly uncover this eye and change to occlude the other eye, without allowing binocular vision whilst moving the occluder between the eyes.
- Occlude this eye for 2 to 3 seconds then quickly occlude the other eye and so forth.
- Observe the refixation movement of the uncovered eye during each passage from one eye to the other.
- While continuing to alternate the occlusion, place the prism bar before one eye and increase the amount of prism in small steps until the refixation movement is neutralised.
- The value of the prism that neutralizes the movement gives the measurement of the phoria..

The prism bar may be used in a similar way to measure fusional reserves:

- **Horizontal reserves**:
  - Have the patient focus on a vertical line of letters of a size appropriate for their level of vision.
  - **For divergence (negative relative convergence):**
    - Place a low power *base in* prism in front of one eye.
    - Increase the value of the prism (every 2 to 3 seconds) until the patient reports that the letters become blur red **(blur)*, then that the line is seen double ***(break)*.
    - Reduce the value of the prism until the patient again sees a single line of letters (*recovery*).
    - Remove the prism bar and note the blur/break/recovery points.
  - **For convergence (positive relative convergence):**
    - Place a low power *base out* prism in front of one eye
    Increase the value of the prism until the patient reports that the letters become blurred *(*blur*), then that the line is seen as double ***(break)*.
    - Reduce the value of the prism until the patient again sees a single line *(recovery)*.

* some patients do not notice the blur point and it may not occur in negative relative convergence
** if the patient does not see double, note the position at which one eye loses fixation

- **Vertical reserves**:
  - Have the patient focus on a horizontal line of letters.
  - Introduce a *base down* prism. Increase the value of the prism progressively until the patient sees the line as double, then reduce the prism until the patient again sees a single line.
  - Repeat the same sequence using *base up* prism.
  - Note the *break and recovery* points. (There is no *blur* point here as vertical vergence movements do not stimulate accommodation).

b) Analyzing phoria:
It is important to emphasize that the size of the phoria is a less important factor than the patient's capacity to compensate for it. In other words, even a significant phoria may pose no difficulty if the patient possesses sufficient fusional reserves to compensate for it comfortably. In practice, phoria would be treated only if the patient suffers symptoms such as asthenopia, double or blurred vision, or fatigue, or shows signs of functional disorders such as abnormally close or far reading distances. Other symptoms including headaches, sore or red eyes, ocular discomfort, watering of the eyes, may be experienced, particularly after prolonged periods of work. (These symptoms are of course not specific to poorly compensated phoria).

This analysis can be performed according to different criteria:

- **Percival's criterion**, which suggests that vergence demand should lie in the middle third of the zone of single clear binocular vision, as demarcated by the blur or break points.
- **Sheard's criterion,** which suggests that 'the fusional reserves opposing the phoria should be equal to at least twice the phoria for the phoria to be correctly compensated'.

These criteria may enable the value of any prismatic prescription, ensuring the binocular comfort of the patient, to be determined.

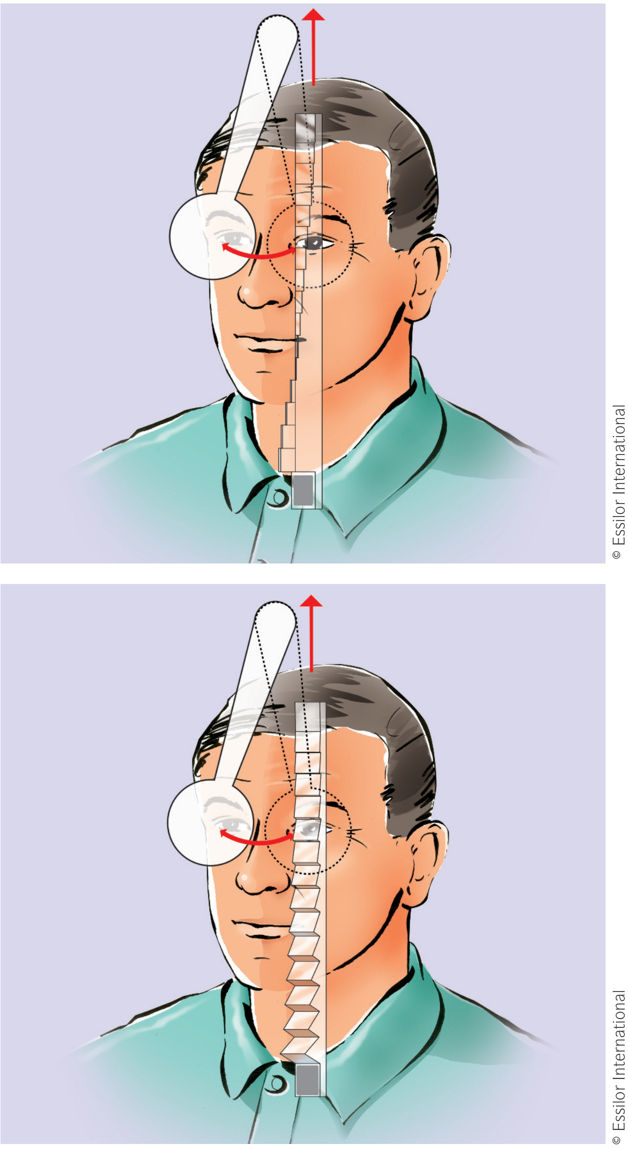


Figure 48: Measuring Phoria and Fusional Reserves

As a general rule, vision training (exercises aimed at developing the patient's fusional reserves) is the treatment of first choice, with the prescribing of prism reserved as a secondary treatment.

3) Assessing and analyzing tropia:

The nature of any tropia must be determined by an in-depth analysis. In particular it is important to discover the following characteristics of a tropia:

- constant or intermittent: is the deviation always present?
- fixed or alternating: is it always the same eye that deviates?
- comitant or non-comitant: is the deviation the same in all directions of gaze?
- accommodative or non-accommodative: does the deviation vary with accommodation? (for example, estropia caused by a large degree of uncorrected hypermetropia)
- recent or longstanding: has it existed for a long time or has it appeared recently?
- progressive or stable? (if progressive, suspect a pathological origin)
- What is the angle of the deviation? Does it vary with the fixation distance?
- Is the tropia accompanied by eccentric fixation or by amblyopia?
- What is the degree of fusion? What is the depth of any suppression?
- etc.

The angle of deviation may be measured by the alternate occlusion method (see above for the measurement of phoria) to determine the value of the prism that neutralizes the refixation movement during the alternating cover test.

Tropia can have multiple causes and treatment is complex. It is vital to check the patient's motor and sensorial binocular vision thoroughly and to identify the cause(s) of the tropia. Once the diagnosis is established, patient care may involve refractive correction, vision training, a prismatic prescription, surgery or other treatment if the cause is of pathological origin. It is clear that the treatment of tropia requires the competence of professional binocular vision specialists. It falls beyond the scope of this file.

C Prescribing Prism

When prism is to be prescribed, the value of the prism must be precisely determined. As a general rule, always seek to prescribe the minimum value of the prism that restores comfortable fusion. Remember that, in effect, prism acts as a surrogate for the eyes, leaves the eye in the deviation ('fixes' the defect) and is even sometimes 'absorbed' by the patient.

With this in mind, it may be advisable to:

a) work with trial frames rather than with the phoropter, in order to allow the patient to maintain peripheral fusion

b) prescribe the minimum prism value that restores fusion in the presence of, for example, a weak fusion dissociator (such as the red filter, described below).

Several methods, based on different principles, may be used to determine the value of the prism to be prescribed. Although these methods are often subject to debate, this file is not the place to discuss their relative merits. Here only one method is detailed, that of the red filter. It may be used at distance and near. The procedure is as follows:

- Have the patient fixate on a point of light.
- Place the red filter over one eye: the patient should see two points of light, one white and the other red.
- Note the position of the white light relative to the red light.
- Place a prism of appropriate power and orientation over the eye without the red filter; the white light moves towards the prism apex.
- Increase the value of the prism very gradually until the patient sees only a single point of light. This per ception must be able to be sustained by the patient (give the patient time to assess and adjust his vision). Note this amount of prism.
- Repeat the procedure, placing the red filter over the other eye and note the amount of prism requi red in this case.
- Choose, as the value of the corrective prism, the lesser of these two amounts of prism which allow restoration of the patient's fusion.

The prism prescription:

- It may be preferable to prescribe an equivalent oblique prism for one eye rather than splitting a horizontal prism before one eye and a vertical prism before the other.
- Distribute most or all of the prism on the non-dominant eye in order to avoid or minimize the risk of disturbing the vision of the dominant eye by the aberrations introduced by the prism.
- Check that a single prism value is acceptable in both distance and near vision; if not, separate distance and near prescriptions will be necessary.
- It may be preferable that the amount of corrective prism be measured on different days or occasions, when the patient is less or more tired, as its measurement may vary; adhesive (Fresnel) prisms (applied to the patient's spectacles) may be used to trial a prism prescription before prescribing.

Many other methods can be used to determine the value of the prism to be prescribed. These include methods based on the measurement of the phoria itself, on the evaluation of the opposing fusional reserve or on the measurement of fixation disparity. Each of these methods has their devotees and their detractors and no one method is unanimously approved. However, notwithstanding the continuing debate, the important thing remains to find a solution to resolve any binocular vision problem the patient may have, either by direct treatment or by referral to an eye care professional specialized in this field.

Definition, Measurement and Summation of Prism

DEFINITION OF PRISM

The official unit of measurement of deviation is the prism dioptre or cm/m symbolized by the Greek letter Delta, ∅. A prism of 1∅ will deviate light rays by 1 cm at a distance of 1 m.

Another unit sometimes used is the prism degree. This is usually the apical angle of the prism but sometimes the deviation produced by the prism, expressed in degrees. For a material of refractive index 1.50 the deviation in degrees is equivalent to half the value of the apical angle of the prism. The prisms in trial sets or prism bars are still often labelled in this unit.

To convert apical angle in degrees to prism dioptres, P, use the trigonometric ratio, P = 100 x tan [(n-1) x a] where P is the prism effect (in ∅), n the refractive index of the material and a the angle of the prism (°) or, more simply, use the table below (calculated for n = 1.5). It shows, for example, that a prism with an apical angle of 10° corresponds to a prism effect of 8.75∅ and, conversely, that a prism effect of 7∅ corresponds to a prism with an apical angle of 8°. The main error committed when converting prism degrees to prism dioptres is an over-estimation of approximately 10 to 15%. This error is negligible when using small angle prisms (less than 10°) and becomes significant only above this range.

Conversion table: prism degrees to prism dioptres

Apicle Angle (in °)	Prism Effect (in ∅	Apical Angle (in °)	Prism Effect (in ∅
1	0.9	11	9.6
2	1.7	12	10.5
3	2.6	13	11.4
4	3.5	14	12.3
5	4.3	15	13.2
6	5.2	16	14.1
7	6.1	17	14.9
8	7.0	18	15.8
9	7.8	19	16.7
10	8.7	20	17.6

GRAPHICAL METHOD OF CALCULATING RESULTANT PRISM

When a prismatic prescription is composed of a horizontal prism and a vertical prism, these can be combined into a resultant oblique prism. The resultant prism is calculated by taking into account both the power and direction of the prisms, rather as vectors are summed. Figure 49 shows a simple graphical solution. Consider the following example of a prism prescription of 4∅ base in and 7∅ base down right: from a perspective of facing the patient, looking at the right eye, start at the origin (centre) of the graph; trace a line on the scale 4 squares to the right (nasally or base in) (representing the horizontal prism); then, from there, trace a line 7 squares downwards (representing the vertical prism, base down). The point reached lies at the intersection of concentric circle 8 and a straight line indicating an angle of 300°. The resultant (oblique) prism is thus a prism of 8∅ base 300.

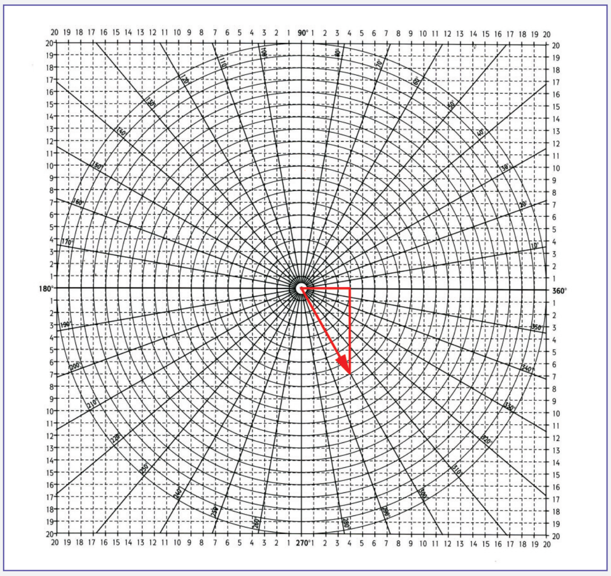


Figure 49: Summation of Prism – Graphical Determination of the Resultant Prism

7. The Prescription (The Final Rx)

The refraction as determined by the above methods is not always what is finally prescribed: this is where the "art" of prescribing comes into play, following the "science" of refraction. There are many factors that may influence the practitioner's decision regarding the final prescription and some of these are discussed below:

- One of the first elements to be considered is the change of correction between the new and previous prescriptions. If a significant change has been determined and is to be prescribed (for example, >0.75 DS sphere, >0.50 DC cylinder, >10° in the axis or >+0.75 D in the addition), patients should be forewarned of the 'learning process' that they will likely have to go through with their new correction. (A patient may find it easier to "work up" to the full change via smaller steps).

- Spectacle lenses are manufactured in 0.25D steps (with standard tolerances) but the eye is a biological organ that does not conform so; often, therefore, during refraction, a choice must be made between two limits of lens steps 0.25D apart. For the spherical component of the correction, it is advisable to err on the side of lesser minus and the maximum plus – *Maximum Plus (Minimum Minus) for Maximum Visual Acuity*.

* In the case of myopia in a younger patient who still has considerable amplitude of accommodation, over-correction (over-minussing) will often be appreciated by the patient because of the greater contrast that it gives. It may be argued that -0.25D over-correction may be acceptable in such a case. However, too much over-correction should be avoided for reasons of visual (accommodative) comfort and that in some cases, progression of myopia may be accelerated by over-correction, particularly when the spectacles are worn for near work.

* In the case of hypermetropia in a younger patient who still has considerable amplitude of accommodation, their correction can be tricky as they have often become used to accommodating and so will not accept their full correction. On the other hand, they are also very sensitive to over-correction and may suffer asthenopia if left too much under-corrected. Patients with hypermetropia should thus be offered the maximum plus power that does not cause any worsening of their distance vision.

** Remember that in the final choice of sphere, the binocular balance and ocular dominance should be respected*

- Remember to take into account the test distance at which the subjective refraction was performed and adjust thereafter for optical infinity. (For example, a subjective refraction conducted at a test distance of 5 metres will be 0.20D (that is, 1/5m (power F (dioptres) = 1/focal distance (metres)) closer than optical infinity and so the sphere may have to be adjusted accordingly (remove +0.25D or add -0.25D)). This is particularly important for refractions conducted at significantly closer distances such as 3m, where the equivalent refractive step is in excess of the 0.25D lens steps able to be prescribed.

- For the cylinder correction, it is preferable to err on the side of the lesser cylinder if a choice has to be made between 0.25D lens steps. Most consider that the least cylinder giving the best vision should be the amount prescribed. There are many schools of thought about prescribing cylinder; in general, the preference is to prescribe the full cylinder correction at precisely the axis found.

- If the cylinder correction is large or significantly different from the previous correction and therefore aniseikonic effects are likely, anticipate this by forewarning the patient; in the vast majority of cases, even with significant cylinder corrections, the patient will appreciate the best corrected visual acuity that the full prescription offers and adapt to any aniseikonic effects within a short period of time. On the rare occasions this is not the case, the cylinder correction or the anisometropia of the cylinder correction may be reduced, bearing in mind that as the cylinder correction is reduced, the sphere should also be adjusted so as to respect the *spherical equivalent* of the full correction (for example, if reducing the cylinder correction in a prescription +6.00/-4.00 x 90 to a cylinder correction of -3.00, adjust the sphere also and prescribe +5.50/-3.00 x 90 so the *spherical equivalent* of +4.00DS is maintained in both the full and reduced prescriptions).

- Generally R/L eyes will be similar (minimal anisometropia) and cylinder axes will be roughly symmetrical around the vertical axis (nose) (for example, R 170, L 10). If there is any significant anisometropia or change in Rx, forewarn the patient of possible aniseikonic effects which may be induced by the new Rx, the adaptation time required and precautions to take in the interim; this will minimise any patient concern and any problems during the learning period.

- For patients with presbyopia, distance vision correction must be accurate for two particular reasons: (i) accommodation is longer present and so any over-correction of myopia or under-correction of the hypermetropia is undesirable and will worsen vision and (ii) any error in the distance correction may be (wrongly) compensated for by increasing the near addition, which will have undesirable consequences. Also, the binocular balance should be respected at both distance and near.

- For patients with presbyopia, for near vision correction, prescribe the minimal near addition required and never over-prescribe the addition. Patients will sometimes indicate preference for stronger additions than are necessary because of the proximal magnification they give, but they also restrict the working distance and reduce depth of field. Prescribing a near addition which is stronger than necessary will have undesirable consequences for the patient's near visual comfort in all types of spectacles (single vision near, bi/trifocals and particularly progressive lenses where this will increase peripheral deformation). Except in very particular cases, the *near additions should always be identical for both eyes.*

- For refractive corrections of 4.00D and greater (plus and minus), vertex distance changes become significant. If a subjective refraction has been determined at a vertex distance which is different from that at which the lenses will be positioned in front of the patient's eyes when wearing the spectacle frame, the final Rx prescribed must be adjusted accordingly. (The effective power of a corrective lens varies with the vertex distance at which it is placed). This adjustment may be avoided by ensuring the subjective refraction is performed at the standard vertex distance of 12-14mm and the patient's spectacle frames are adjusted to this same vertex distance.

- As a general rule, *if a choice must be made*, give priority to *visual comfort over visual acuity.* Remember that acuity is only one element of vision and the only one considered during refraction. Other factors, such as peripheral perception of forms or movement, also contribute to the visual comfort of the patient. This is why the prescription should always be submitted to the 'perceptual appreciation' of the patient. At the end of the examination, always test the correction in a 'real life' situation in a trial frame. Ask patients to assess their visual comfort, not only in distance and near vision but also in terms of looking around at their immediate surroundings. The patient's opinion, often enlightened and relevant, may prove invaluable in the final choice of the correction.

- Aside from the optical considerations listed above, there are many and varied ergonomic and practical issues to consider when choosing the final prescription for the patient. This is when the case history becomes important again, as it is by knowing the patient's visual needs, work environment, leisure activities and such like that the eye care professional may best advise the patient as to the most appropriate kinds of refractive correction to suit those different tasks. No one corrective lens is perfect; different types of lenses suit different tasks. Determining the best form of the prescription for your patient is part of the art of prescribing. Discuss with them the situations and tasks for which the spectacles (or contact lenses, etc) are to be used and explain that different types of lenses may be required for different tasks. Spectacle lenses exist in single vision, bifocal, trifocal, progressive and various occupational forms, and there are many different kinds of each. There are the choices of lens material, tint, coatings, etc to be considered also.

All of these considerations go into the process of deciding on the final prescription or prescriptions.

The few indications presented in this section are shared reflections based on the experience of a group of practitioners. They are in no way intended to represent absolute rules of prescription and are of course always open to discussion.

Conclusion

Refraction is a science but also an art. It is, primarily, the technique of determining and correcting refractive errors of the eye. However, it is also the art of knowing which prescription to choose in order to offer patients both the best possible vision and the best possible comfort. If the technique of refraction can be taught, the art of prescription can only be acquired with practice and clinical experience.

This Ophthalmic Optics File 'Practical Refraction' is designed to share the fundamentals of one technique of refraction. The approach is deliberately practical, with theoretical considerations limited to a minimum. It goes without saying that a subject as vast as this cannot be dealt with fully in such a short file. Readers are thus advised to refer to the many existing publications on refraction and visual examination in order to further their knowledge. Although a few general guidelines regarding prescription have been provided, nothing less than regular practice will enable the eye care professional to acquire not only the technical skills required to practise refraction but also the experience and clinical judgment required to make the best choice of prescription for each patient.

Hopefully, this file will help eye care professionals in their daily refraction practice. Above all it is hoped that it will enable them to prescribe the best possible optical corrections, so as to assist their patients always to 'see better to live better'!

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