ASTIGMATISM

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INTRODUCTION AND OVERVIEW

This chapter includes a review of:

- Classification of astigmatism
- Schematic eye models for astigmatism
- Image formation: uncorrected astigmats
- Vision in uncorrected astigmats
- Effects of correcting lenses on the retinal image size
- Ocular accommodation in corrected astigmats

Astigmatism (**a** = not, **stigma** = point) is an ametropia that exists when the rays from a distant point source are not focused by the eye's optical system to a single point (i.e. when the eye does not form a point image for a distant point object). Instead, the image of a point object consists of two perpendicular line foci that are separated by a given distance. Astigmatism is the most common ametropia in the human population. Almost every eye (about 90%) exhibits a measurable degree of astimagtism, but fortunately the magnitude of this ametropia is relatively small in most individuals.

The most common cause for astigmatism is a toroidal refracting surface. The anterior corneal surface, for example, is usually not spherical (i.e. the power of the cornea is not the same in all meridians). The posterior corneal surface, as well as the surfaces of the crystalline lens, may also be astigmatic. However, even when the corneal and lenticular surfaces are spherical, a decentration or tilting of the crystalline lens with respect to the optical axis of the cornea would cause ‘oblique astigmatism’ and contribute to the eye's total astigmatism.

CLASSIFICATION OF ASTIGMATISM

The type of astigmatism that is associated with an unaccommodated eye is typically classified on the basis of the positions with respect to the retina of the two line foci formed for a distant point source and on the basis of the positions of the principal meridians, i.e. the meridians with the most and least refracting power. If the most powerful meridian is approximately vertical (+/− 30 deg), the astigmatism is classified as ‘with-the-rule’. If the most powerful meridian is near horizontal (+/− 30 deg), it is referred to as ‘against-the-rule’. The term ‘oblique astigmatism’ is used to describe the situation when the principal meridians are within 15 deg of the 45 or 135 deg axes.

Figure 7.1 below illustrates the classification of astigmatic refractive errors according to the relative positions of the line foci (i.e. the images of a distant point source) with respect to the retina.

7.1a represents a **compound myopic astigmatism**. The term 'compound' indicates that both line foci are located on the same side of the retina. In this particular case, both foci are located in the vitreous indicating that both principal meridians have myopic refractive errors.

7.1b represents a **simple myopic astigmatism**. 'Simple' indicates that one meridian is emmetropic, i.e. one-line foci is formed on the retina.

7.1c is a **mixed astigmatism** which means that one meridian is myopic and its line focus is in front of the vitreous, but that the other meridian is hyperopic and its line focus is behind the retina.

7.1d illustrates a **simple hyperopic astigmatism**. One line focus is formed on the retina while the other line focus is formed behind the retina.

7.1e represents a **compound hyperopic astigmatism** where both meridians are hyperopic and their respective line foci are formed behind the retina.

In the following sections we will consider three aspects of the optics of astigmatic eyes:

1) Image formation in the uncorrected condition,
2) Effects of spectacles and contact lenses on the size and shape of the retinal image, and
3) Ocular accommodative requirements in corrected astigmatic eyes.

As with spherical ametropias, many of these issues are best studied using a reduced schematic eye.

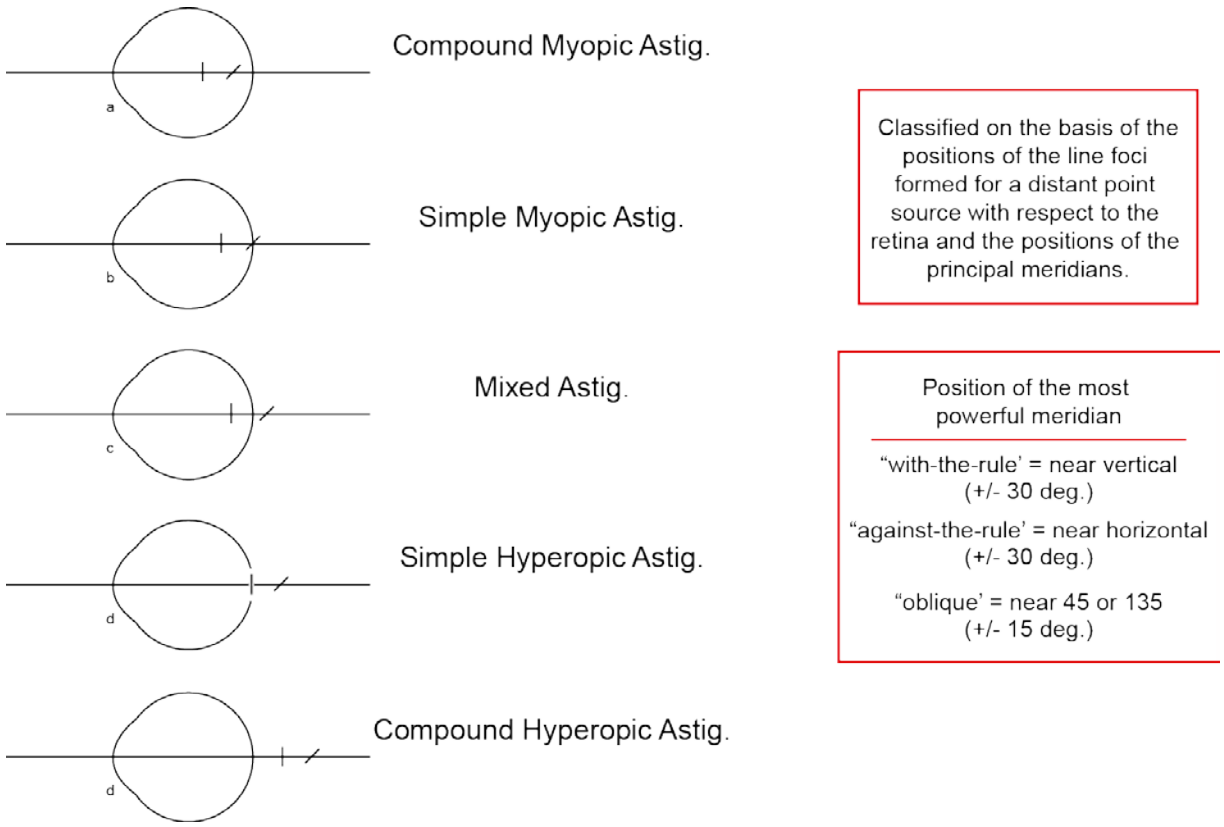


Figure 7.1: *Different classifications of astigmatism. (from H. Obstfeld, Optics in Vision. Butterworth, London, 1982)*

SCHEMATIC EYE MODELS FOR ASTIGMATISM

Astigmatism is a refractive ametropia. Since reduced eye models have a single equivalent refracting surface, astigmatic eyes are modeled by using reduced eyes with a toroidal or astigmatic refracting surface. Since each principal meridian will have its own refractive error, each principal meridian will also have its own far point, its own focal points, and its own nodal point. The principal planes for the principal meridians will coincide with the apex of the equivalent refracting surface. Of course there can only be one axial length, however, individuals with astigmatism can also have a spherical ametropia which is axial in nature. In other words, the distance between the principal plane of an astigmatic eye is not always going to be equal to that for an individual with a spherical, refractive ametropia (i.e. 22.22 mm). See Figure 7.2.

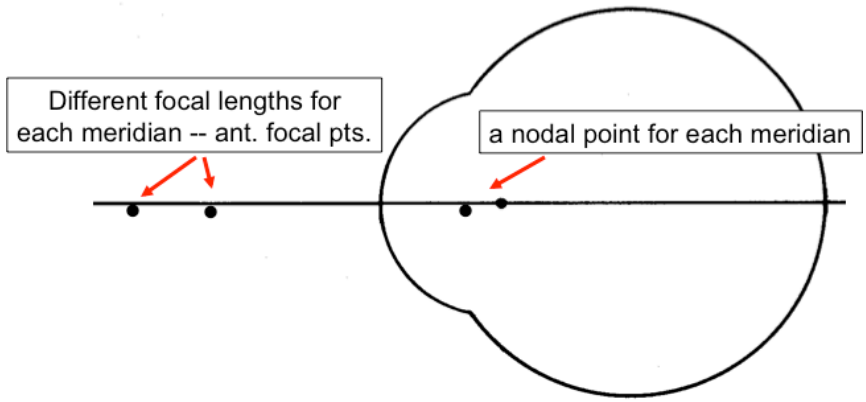


Figure 7.2: *In astigmatism, each meridian will have a different anterior focal point and nodal point*

IMAGE FORMATION: UNCORRECTED ASTIGMATS

The visual acuity of uncorrected astigmats will be influenced by the type of astigmatism and the spatial characteristics of the optotypes employed to measure visual acuity. The effects of astigmatism on the retinal image and, hence visual performance, can be appreciated by considering the effects of this ametropia on the shape of the retinal image of a distant point source and on the shape of the retinal image for an extended object. The necessary calculations are virtually identical to those described in Chapter 4 for spherical ametropia, however, with astigmats it is necessary to perform these calculations for both principal meridians. In essence, it is analogous to calculating image size for two different eyes which each represent one of the principal meridians.

Assume that a patient has a compound, myopic, with-the-rule astigmatism and an ocular refractive error of -5.00/ -5.00 X 180. Also assume that this patient's spherical ametropia is refractive in nature (i.e. the distance between the principal plane and retina is 22.22 mm) and that the patient's pupil is 10 mm in diameter (and as in spherical ametropias is located at the principal plane).

POINT OBJECT

The shape of the retinal image of a distant point source can be obtained by considering the positions of the line foci with respect to the retina. Figure 7.3 illustrates the astigmatic pencil produced by superimposing the cross-sections in the two principal meridians. As shown by the inset in Fig 7.3, the ocular refractive errors for the horizontal and vertical meridians are -5.00 D and -10.00 D, respectively. Consequently, the total refractive power of the vertical meridian of the eye will be +70 D (i.e. 10 D more power than an emmetropic eye) while the refractive power of the horizontal meridian will be +65 D. The light rays from the distant object that impinge on the vertical meridian will, after refraction, converge to form a horizontal line focus at point 3 and subsequently diverge in the vertical dimension as these rays approach the retina. Rays that impinge on the horizontal meridian of this eye will converge to form a vertical line focus. Since the horizontal meridian is less myopic than the vertical meridian, the resulting vertical line focus will be formed at a greater distance from the equivalent refracting surface and concomitantly closer to the retina. After forming the vertical line focus at the point 7, the light refracted by the horizontal meridian will diverge toward the retina in the horizontal meridian after point 7.

The horizontal and vertical dimensions of the retinal image are delineated by the rays that enter the optical system at the margins of the pupil (as represented by the rays in 7.3). As can be seen in 7.3, after forming the horizontal line focus at 3, the light rays refracted by the vertical meridian will diverge more before they intersect the retina than the rays refracted by the horizontal meridian (which come to a focus at 7). Since the pupil, which is the limiting aperture of the eye, is circular, the cross section of the refracted pencil at the retinal surface will be elliptical with, in this case, its long axis vertical. However, it should be appreciated that the cross-sectional shape of the refracted pencil will vary in size and shape with distance from the equivalent refracting surface. For example, if the retina was moved forward so that it was located in front of point 3, the resulting retinal image would again be elliptical, but in this instance the long axis of the ellipse would be horizontal. Of course, if the retina was at either points 3 or f_h, the refracted pencil would form a line. The retinal image would be circular if the retina was located at the circle of least confusion, i.e. the dioptric midpoint between the secondary focal points of the horizontal and vertical meridians.

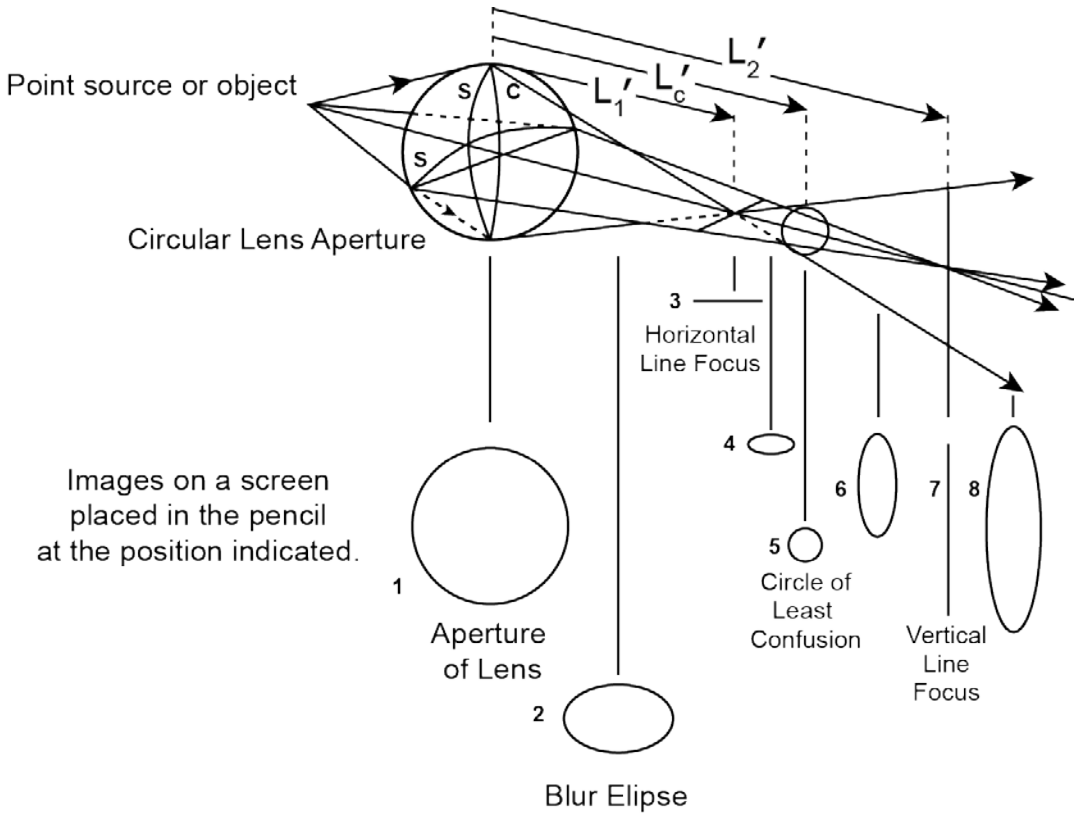


Figure 7.3: *Astigmatic pencil for a system with a circular aperture*

The physical dimensions of the elliptical retinal image can be calculated using a geometric approach. The position of the line focus for each meridian must be calculated and then the respective retinal dimensions can be calculated using relationships for similar triangles.

For the **vertical meridian**:

Vergence of light after refraction

$L'_v = L + F$
$L'_v = 0 + 70\ D = 70\ D$

Image position

$l'_v = n' / L'_v$
$l'_v = 1.333 / 70\ D$
$l'_v = 0.01905\ m$

i.e. the horizontal line focus is formed 19.05 mm from the eye's principal plane and 3.17 mm in front of the retina (22.22 mm - 19.05 mm).

From Fig 7.3, you can see that the triangle formed by the pupil as its base and point 3 as its apex is similar to the triangle formed by the vertical dimension of the retinal image and point 3. Hence, the vertical image size (h'_v) can be calculated using the following relationship, i.e. the ratios of the bases and altitudes of similar triangles.

Vertical image size

h'_v / 3.17 mm = pupil size / 19.05 mm
h'_v = (10 mm / 19.05 mm) (3.17 mm)
h'_v = 1.66 mm

i.e. the vertical dimension or the long axis of the retinal image is 1.66 mm.

For the **horizontal meridian**:

Vergence of light after refraction

$L'_h = L + F_h$
L'_h = 0 + 65 D = +65D

Image position

$l'_h = n' / L'_h$
l'_h = 1.333 / 65 D
l'_h = 0.02051 m

i.e. the vertical line focus is formed 20.51 mm behind the eye's equivalent refracting surface and 1.71 mm in front of the retina.

Horizontal image size

h'_h / 1.71 mm = 10 mm / 20.51 mm
h'_h = (10 X 1.71 mm) / 20.51 mm
h'_h = 0.834 mm

Hence, the horizontal dimension of the retinal image is 0.834 mm, essentially half the size of the vertical dimension.

EXTENDED OBJECT

The 'defined' retinal image size of an extended object in an uncorrected astigmatic eye can be calculated by considering the chief rays in the two principal meridians. In Figure 7.4a the chief rays and the astigmatic pencils for the two principal meridians of our uncorrected compound myopic astigmat (-5.00 / - 5.00 X 180) are shown as superimposed, cross sections. In this example, the distant object is a square (with vertical sides and horizontal top and bottom borders); the sides of the square subtend visual angles of 0.1 radians at the eye's principal plane. Although the eye's two meridians have different refractive powers, the two chief rays are virtually identical because in this case the ametropia, both the spheric and astigmatic components, is refractive in nature. Consequently, the defined retinal image size will be the same for the two meridians and can be calculated by multiplying the angle of refraction associated with the chief rays by the distance between the principal plane and the retina.

Angle of refraction (for both meridians)

i' = i / n'
i' = (0.75)(0.1rad) = 0.075 rad

Retinal image size (for both meridians)

h' = (0.075 rad) (22.22 mm)
h' = 1.67 mm

Hence, the retinal image will be square and the horizontal and vertical dimensions will be 1.67 mm.

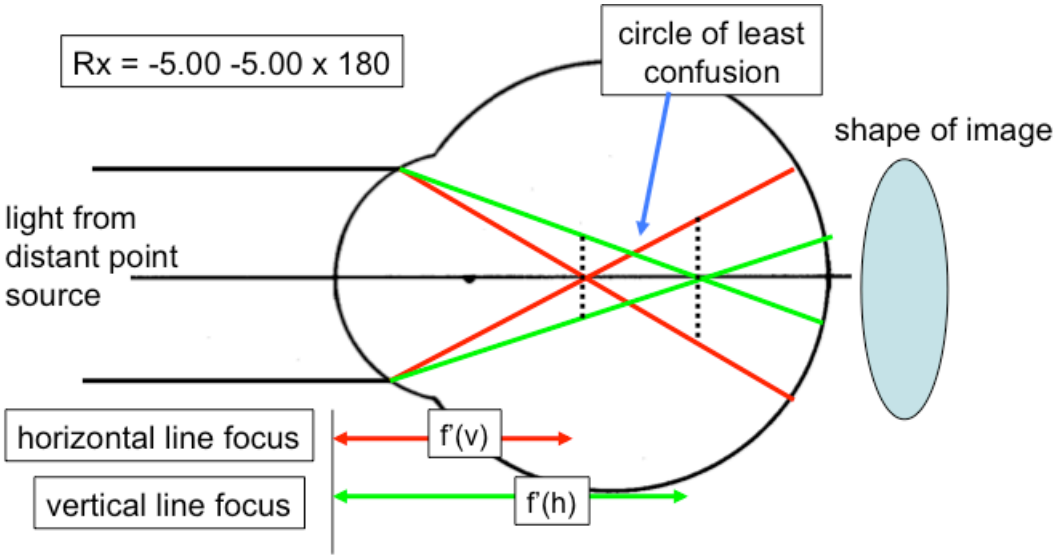


Figure 7.4a: *Retinal image in uncorrected astigmatic eye – point source*

Since each point of the uncorrected retinal image will be a vertically oriented blur 'oval', the **true** physical size of the retinal image is larger than that described by the chief rays and will, in this case, be asymmetrical. As shown by the inset in Fig 7.4b, the vertical sides of the retinal image will be 3.33 mm long. This value was determined by adding the length that the blur ellipses extend beyond the top and bottom of the defined image size (i.e. 1.66 mm, the dimension of the long axis of the blur ellipse) to the 'defined' image size determined by the chief ray. The overall dimension of the image in the horizontal meridian will be 2.50 mm (1.67 mm plus 0.834 mm).

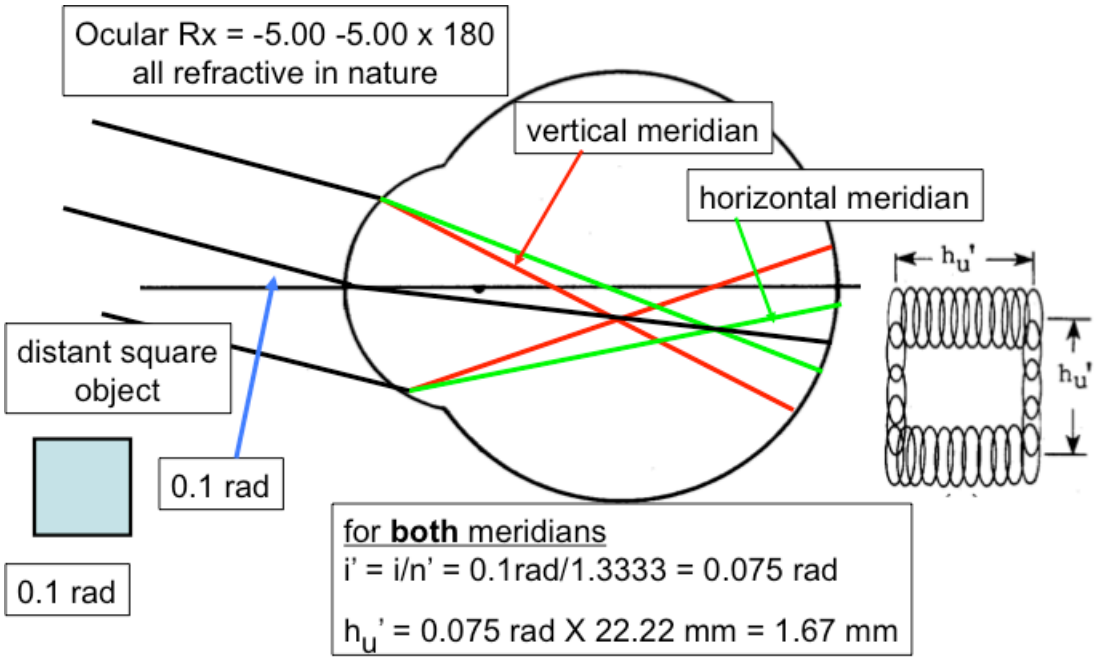


Figure 7.4b: *Retinal image size in uncorrected astigmatic eye – distant square object*

Note: In an astigmatic eye, the orientation of the line focus that is farthest away from the eye's principal plane will always be parallel to the ocular meridian that has the highest plus refracting power and, thus, 90 deg away from the axis of the minus cylinder correcting lens. It is important to keep this relationship in mind when you are using the clock-dial target or astigmatic chart to determine the appropriate cylinder axis for your patient. In order to properly interpret the findings for an astigmatic chart, it is critical to ensure that a sufficient amount of plus lens fog is employed. You must add enough plus power to position both line foci in the vitreous in front of the retina. In this situation, you can be assured that the more posterior line focus will be closer to the retina and the patient will see the lines on the astigmatic chart that are parallel to the most powerful ocular meridian as darker and more distinct than all the other lines.

VISION IN UNCORRECTED ASTIGMATS

Because the overall image in an uncorrected astigmatic eye is usually asymmetrical (anytime the circle of least confusion does not fall on the retina), astigmats can usually see some visual targets better than others. In this respect, the exact visual deficits will depend upon the magnitude and classification of the astigmatism and also upon the type of visual stimulus that is employed. For example, consider two E targets. In both instances the vertically oriented features of these targets would be distorted to a lesser extent than the horizontal features (for the with-the-rule, compound myopic astigmat described above). However, since the critical features of the rotated E are vertical, the uncorrected astigmat described above would be able to resolve the rotated E more easily than the traditionally oriented E. And as one would expect, if asked which lines on a clock-dial astigmatic chart were the clearest, this patient would report that the 12:00 to 6:00 lines were the most distinct (i.e. less blurred).

Traditional Snellen acuity charts are made up of capital, block letters which are dominated by horizontal and vertical components. With- and against-the-rule astigmats that have equal magnitude refractive errors will typically have about the same visual acuities for these charts. The visibility of any given letter will depend upon which line foci is closest to the retina and the exact shape of the letter. Consequently, for lines of letters near the resolution limit, uncorrected astigmats will correctly identify some letters and not others (i.e. they will often miss at least some letters on several lines before they reach a line of letters that are simply too small to read any). (Figure 7.5) Individuals with oblique astigmatism of equal magnitude will usually exhibit a lower visual acuity than with- or against-the-rule astigmats because both the horizontal and vertical features of the Snellen chart will be defocused and few Snellen letters have critical features that are obliquely oriented. (Figure 7.6)

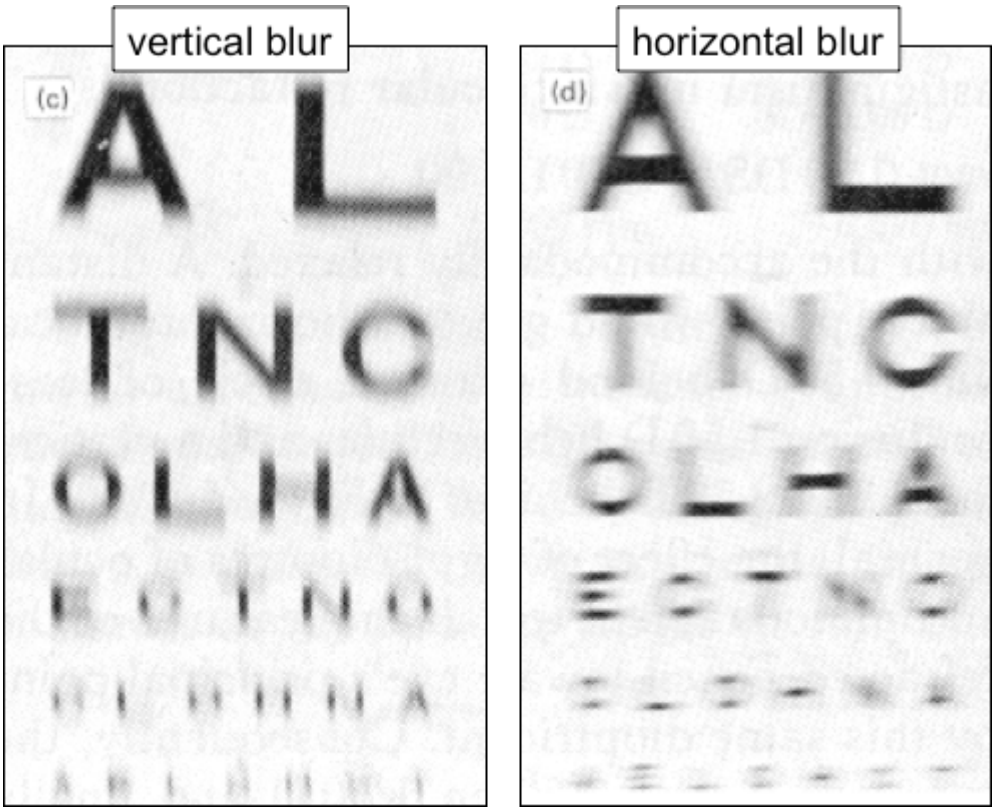


Figure 7.5: *Vision in uncorrected astigmats – 'with the rule' (L) and 'against the rule' (R)*

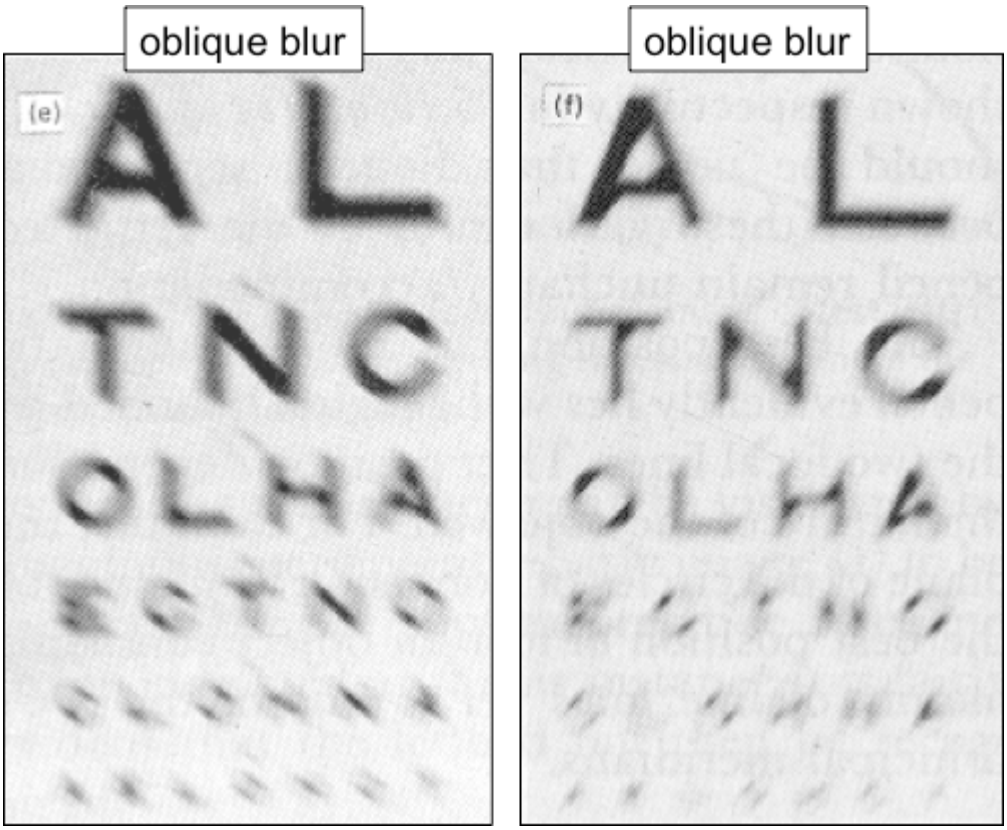


Figure 7.6: *Vision in uncorrected astigmats – 45 degrees (L) and 135 degrees (R)*

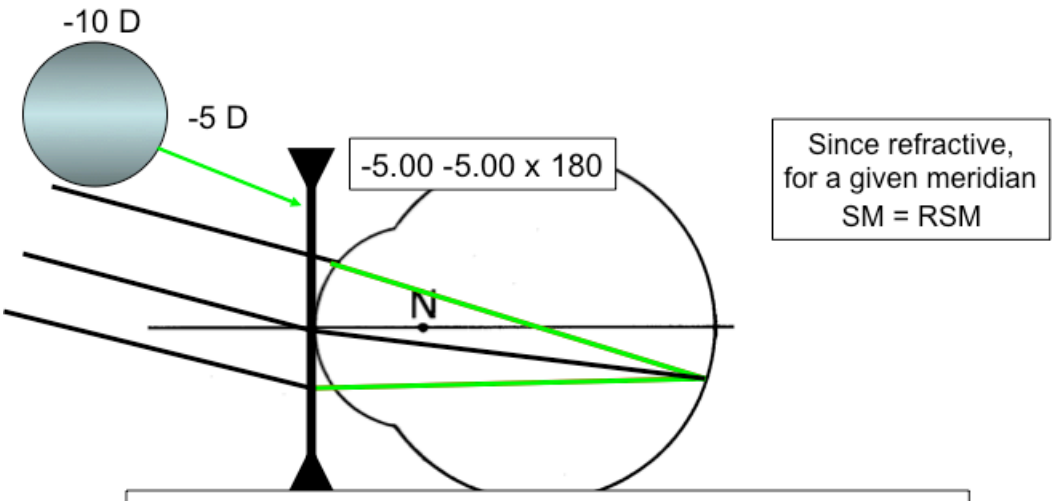
In some cases, Snellen acuity can overestimate the visual performance of uncorrected astigmats on other visual tasks. For example, unlike capital letters, lower-case letters are dominated by vertical components and these vertical components are critical for letter recognition. Moreover, in printed material the horizontal distance between adjacent letters is smaller than the vertical space between lines of letters. As a result, astigmats that have horizontally oriented blur ellipses being formed on their retinas will not be able to read lower case printed material as well as astigmats which have vertically oriented blur ovals (assuming that the astigmats have the same Snellen acuity). The greater defocus in the horizontal meridian will mask critical letter features and cause adjacent letters to run together, i.e. these astigmats would function below their Snellen acuity level when viewing lower case printed material.

EFFECTS OF CORRECTING LENSES ON THE RETINAL IMAGE SIZE

Considering retinal image size in corrected astigmatic eyes is somewhat analogous to comparing retinal images between two eyes that have different refractive errors. In essence, in astigmats we must examine the effects of refraction in both principal meridians in order to determine the effects of correcting lenses on retinal image size. In other words, we must determine RSM and SM for both meridians

CONTACT LENSES

Contact lenses and spectacle lenses have very different effects on the retinal images formed in astigmatic eyes. As discussed in Chapter 4, SM will equal 1.0 when refractive ametropes are corrected with contact lenses (assuming that the contact lens is placed on the eye's principal plane). Since astigmatism is a refractive ametropia, SM will be the same for both principal meridians when astigmats are fitted with contact lenses. Consider the astigmatic eye described above (see Fig 7.7). The eye had an ocular Rx of -5.00 / -5.00 X 180 and the entire ametropia (both sphere and cylinder) was refractive in nature (i.e. the distance between the principal plane and retina will be equal to that in an emmetropic eye, 22.22 mm). What would be the RSM and SM for the principal meridians when the eye was corrected with contact lenses placed at the eye's principal plane?



$$\text{RSM} = \frac{F(\text{emmetrope})}{F_{eye} + F_{lens} - d(F_{eye})(F_{lens})}.$$

$$\text{vertical RSM} = \frac{+60\text{ D}}{+70\text{D} - 10\text{D} - [0.0\text{m}(70\text{D})(-10\text{D})]} = \frac{60}{60} = 1.0$$

$$\text{horizontal RSM} = \frac{+60\text{ D}}{+65\text{D} - 5\text{ D} - [0.0\text{m}(65\text{D})(-5\text{D})]} = \frac{60}{60} = 1.0$$

Figure 7.7: *Relative spectacle magnification with contact lens correction of astigmatism*

Because the ametropia is entirely refractive in nature, SM will equal RSM and the easiest way to determine these values is to consider the equivalent power of the eye lens combination in both principal meridians.

For the vertical meridian

F_{lens} = -10.0 D
F_{eye} = +70.0 D

RSM = ($F_{emmetrope}$) / ($F_{ametropiceye\text{-}lens\ combination}$)
RSM = +60 D / +70.0 D − 10.0 D − [(0)(70.0D)(−10.0D)]
RSM = 60.0 D / 60.0 D

Hence,RSM = SM = 1.0

For the horizontal meridian

F_{lens} = −5.00 D
F_{eye} = +65.0 D

RSM = +60.0 D / +65.0 D − 5.0 D

Hence,RSM = SM = 1.0

For this astigmatic eye the retinal image will be identical in every respect to that formed in an emmetropic eye, i.e. both the size and shape of the image will be the same as that in an emmetrope.

The SM for both principal meridians will always equal 1.0 when astigmats are corrected at the principal plane. However, if the astigmat also has a spherical ametropia that is axial in nature, RSM for a given meridian will not equal SM although the RSMs for the two principal meridians will be equal. For instance, in the example above, the spherical component of the refractive error could have been axial in nature, i.e. in addition to having a cornea that had 5.0 D of astigmatism, the axial length of the eye could have been longer than normal. In this situation, RSM would have been greater than 1.0 for both meridians, but SM would still be equal to 1.0 (see Chapter 4 and the effects of contact lenses on RSM in axial myopes).

SPECTACLE LENSES

In refractive ametropia corrected with spectacles, RSM and SM vary as a function of the power and position of the correcting lens. As a result, when astigmats are corrected with spectacles, RSM and SM for the two principal meridians can be quite different. To illustrate this point consider the effects of correcting the compound myopic astigmat described above with spectacles positioned 15 mm in front of the eye's principal plane (see Fig 7.8). Again, we will assume that the refractive error is entirely refractive in nature and that the patient's ocular Rx is -5.00 / -5.00 X 180.

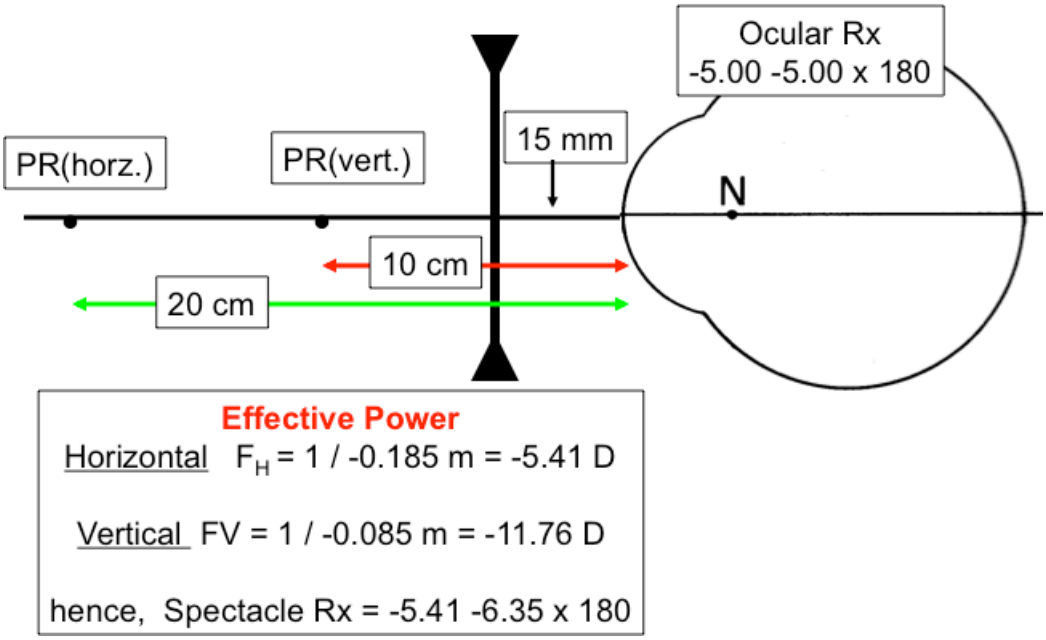


Figure 7.8: *Spectacle correction of astigmatism*

First, calculate the appropriate equivalent power for the spectacle plane.

For the **horizontal meridian**

The eye's far point for the horizontal meridian is 20 cm (1 / -5.0 D) in front of the principal plane. The new spectacle plane is 1.5 cm in front of the eye's principal plane, hence, the horizontal meridian of the spectacle lens must have a secondary focal length of -18.5 cm (20 - 1.5 cm). Therefore, the power of the spectacle lens in the horizontal meridian must be:

$F_h = 1 / -0.185$ m
$F_h = -5.41$ D

For the **vertical meridian**

The eye's far point for the vertical meridian is 10 cm in front of the eye's principal plane and, hence, 8.5 cm in front of the spectacle plane. Therefore, the power of the spectacle lens in the vertical meridian must be:

$F_v = 1 / -0.085$ m
$F_v = -11.76$ D

Thus, the spectacle Rx is: −5.41/−6.35 × 180.

Since the ametropia is entirely refractive, RSM = SM for a given meridian and either of these values can be calculated in several ways. The two most straight forward strategies involve calculating RSM using the equivalent power approach and SM using the relation between the far point and the spectacle lens.

RSM for the horizontal meridian

F_{lens} = −5.41 D
F_{eye} = +65.0 D
$F_{emmetrope}$ = +60.0 D
t = 0.015 m

$RSM_h = F_{emmetrope} / F_{eye} + F_{lens} - [t(F_{eye})(F_{lens})]$
RSM_h = 60.0 D / 65.0 D − 5.41 D − [(0.015 m)(65.0 D)(−5.41 D)]
RSM_h = 60.0 D / 64.86 D
RSM_h = 0.925

RSM for the vertical meridian

F_{lens} = −11.76 D
F_{eye} = +70.0 D

RSM_v = 60.0 D / 70.0 D − 11.76 D − [(0.015 m)(70.0 D)(−11.76 D)]
RSM_v = 60.0 D / 70.59 D
RSM_v = 0.85

SM for the horizontal meridian

SM_h = (distance between PR_h and spect. plane) / (distance between PR_h and principal plane)
SM_h = 18.5 cm / 20.0 cm
SM_h = 0.925

SM for the vertical meridian

SM_v = 0.85 cm / 10.0 cm
SM_v = 0.85

The above calculations indicate that the spectacle lens minified the retinal image relative to both the uncorrected case and the standard emmetropic eye. But more importantly, they demonstrate that the magnification for an extended, in-focus retinal image will be different for the two principal meridians, i.e. the retinal image will be distorted so that the shape of the retinal image will not be identical to the shape of its object. Consider the shape of the resulting retinal image for a distant square object that has horizontal and vertical sides that subtend visual angles of 0.1 radians. As demonstrated on page 7, the defined retinal image for this object in the uncorrected state would be a square with sides that were 1.67 mm long (this object would also produce a 1.67 mm square image in an emmetropic eye). To determine the size of the retinal image in the corrected state, you can multiply the size of the uncorrected retinal image by the SM for each meridian keeping in mind that the SM for the horizontal meridian determines the horizontal dimensions of the in-focus retinal image and the SM for the vertical meridian determines the vertical dimensions. So, for this example the dimensions of the corrected retinal image would be:

Horizontal meridian

$h'_h = SM_h \times$ (uncorrected horizontal image size)
h'_h = 0.925 × 1.67 mm
h'_h = 1.54 mm

Note: This would be the dimensions for both the horizontal and vertical sides of the retinal image formed in a **spherical** myopic eye that had a -5.41 D refractive ametropia.

Vertical meridian

$h'_v = 0.85 \text{ X } 1.67 \text{ mm}$

$h'_v = 1.42 \text{ mm}$

Hence, the resulting in-focus retinal image of the distant square object would be a rectangle with the long axis of the rectangle oriented horizontally. An important rule of thumb to remember is that the greatest image magnification (i.e. the largest image size) in a corrected astigmatic eye will always be parallel to the axis of the minus cylinder correcting lens (in this case the horizontal meridian).

At first glance, the above example might seem confusing. In uncorrected astigmatic eyes, the vertical meridian produces a horizontal line focus for each distant point source while the horizontal meridian produces a vertical line focus. Remember that in the above example, we were dealing with an *extended* object and an *in-focus* image. The resulting differences in image size reflect the differences in the sizes of the images of distant objects formed by the two meridians of the correcting lens at the eye's two far points. As shown in Fig 7.9, the image of a distant square formed by the horizontal and vertical meridians of the spectacle lens used in the above example can be illustrated by considering the rays from the extreme points of the object that pass through the optical center of the correcting lens (again, the two principal meridians are illustrated as superimposed cross-sections). The image formed at the far point for the eye's horizontal meridian by the power in the horizontal meridian of the lens will be a square 18.5 cm in front of the lens. Each point of this square will, in fact, be a vertical line (i.e. the line focus formed by the horizontal meridian of the lens). The vertical meridian of the lens will form a square image at the vertical far point located 8.5 cm in front of the lens. Again, the image of the distant square object will be a square, but each point will be represented as a horizontal line. Obviously, the image formed at the horizontal far point is physically the largest, but the point to note is that the angle of incidence at the eye's principal plane will be different for these two images. And in this case, the angle of incidence of the chief rays from the image at the horizontal far point will be larger than that for the image at the vertical far point. Consequently, since the axial length of the eye is the same for both meridians, the resulting retinal image will be larger in the horizontal meridian.

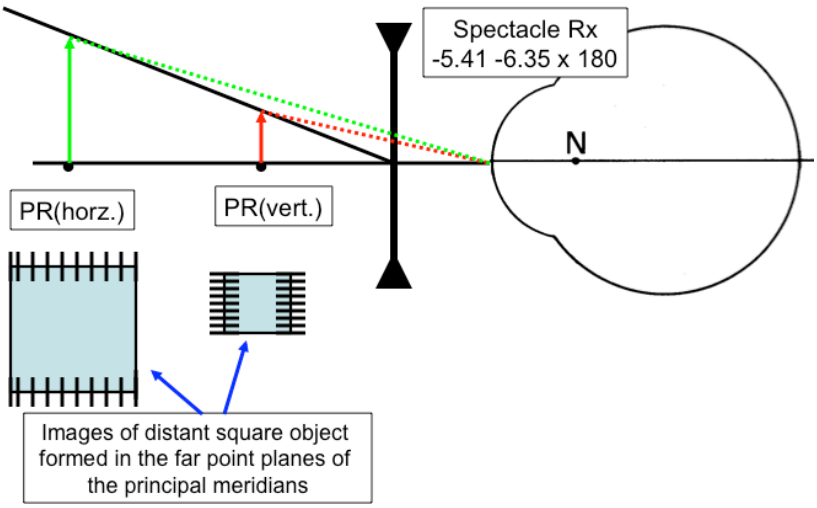


Figure 7.9: *Image of a distant squareformed by horizontal and vertical meridians of the spectacle lens*

Note: Consider what would happen to the images in Fig 7.10 if you placed a stenopaic slit in front of the correcting lens; first with the slit oriented horizontally and then when it was oriented horizontally. A stenopaic slit is an opaque disc that has a central slit aperture that is about 1mm in width (in essence an elongated pinhole). These simple devices were once commonly used to test for astigmatism. By placing the slit at a particular orientation you are, in a sense, isolating the power of one meridian and reducing the optics of an astigmatic system to that of a spherical system. Astigmatic individuals would exhibit different refractive errors that would vary as a function of slit orientation.

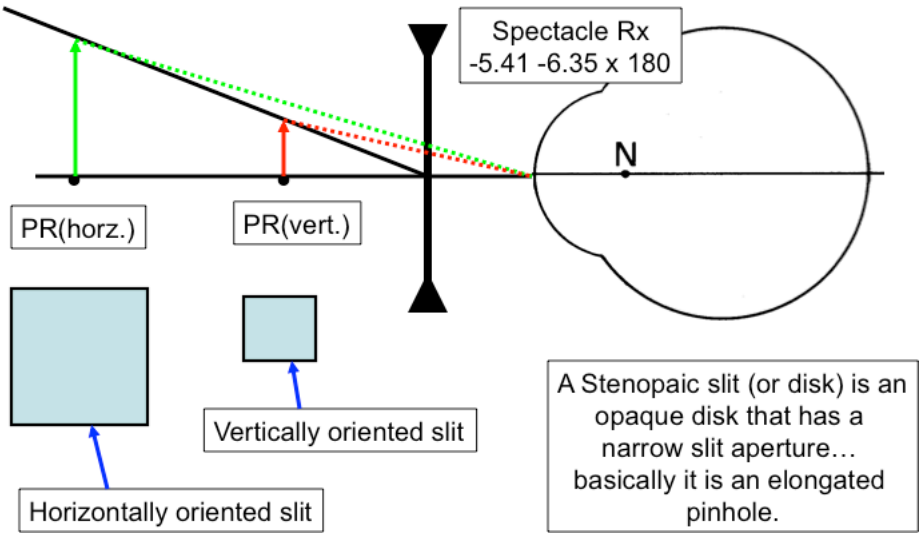


Figure 7.10: *Impact of a stenopaic slit on retinal images formed by spectacle lenses*

As discussed in Chapter 4interocular differences in image size can produce distortions in perceived visual space and, if large enough, disrupt fusion. Consider the following two individuals. Both patients have emmetropic left eyes. The right eye of patient A has a -5.00 DS refractive myopia. The right eye of the patient B has simple myopic astigmatism which is also refractive in nature (pl / -5.00 X 180). Assume both patients are corrected with spectacles positioned 15 mm in front of the eye's principal plane. In patient A, the right eye image would be smaller than that in the right eye (about 7.5%), but the shapes would be identical. In patient B, the horizontal dimensions of the right eye image would be the same as that in the left eye, however, the vertical dimensions in the right eye would be smaller than those in the left eye, i.e. the shapes of the left and right eye images of patient B would be different. Which patient would you think might have difficulties associated with anisekonia?

Although in some sense patient A would have the biggest interocular retinal image differences (e.g. in terms of area), patient B is more likely to exhibit symptoms associated with anisekonia. In general, overall interocular differences in magnification affect the ability to fuse the images from the two eyes. On the other hand, meridional differences associated with astigmatism produce much larger distortions in perceived space. Often when an individual is given a new Rx which produces a meridional, interocular difference in image size, the patient will report that their vision is clear, but things ‘look funny’ through the new Rx (or things just don't look right). It is important for the optometrist to recognize when a new Rx will potentially alter the habitual interocular balance in retinal image size. In many cases, the patient will rapidly adapt to the new imbalance if they are appropriately counseled. However, in some cases it may be necessary to resort to a new form of correction. It is also important to recognize that a patient who has adapted to an interocular imbalance may temporarily report similar symptoms if they are corrected with a new Rx that eliminates this imbalance (e.g. switching patient B from spectacles to contact lenses).

SHAPE FACTOR MAGNIFICATION

As discussed in the chapter on aphakia, angular magnification can also be produced by the shape of the correcting spectacle lens. In general with spherical ametropias, shape magnification only becomes significant with high-powered plus lenses. However, in astigmats the design of spectacle lenses can significantly affect meridional differences in retinal image size even for relatively low powered cylinders. Remember that the shape factor S is directly proportional to lens thickness and to the power of the front surface of the spectacle lens. Consider the potential differences between plus cylinder and minus cylinder spectacle lens. With minus cylinder lenses, the front surface is spherical; the back surface is cylindrical. On the other hand, with plus cylinder lenses, the back surface is spherical while the front surface is cylindrical. As a result, the degree of shape magnification will be different in the principal meridians of plus cylinder lenses (the shape factor is constant in all meridians for minus cylinder lenses).

Consequently, one should be aware that changing the form of a spectacle lens from the plus to the minus cylinder form and, vice versa, could have effects similar to those described above for the power of astigmatic corrections. In fact, patients who inadvertently have the form of their correcting lenses changed often report similar symptoms (e.g. the new pair of spectacles makes things look funny) (see Figure 7.11, 7.12 and 7.13).

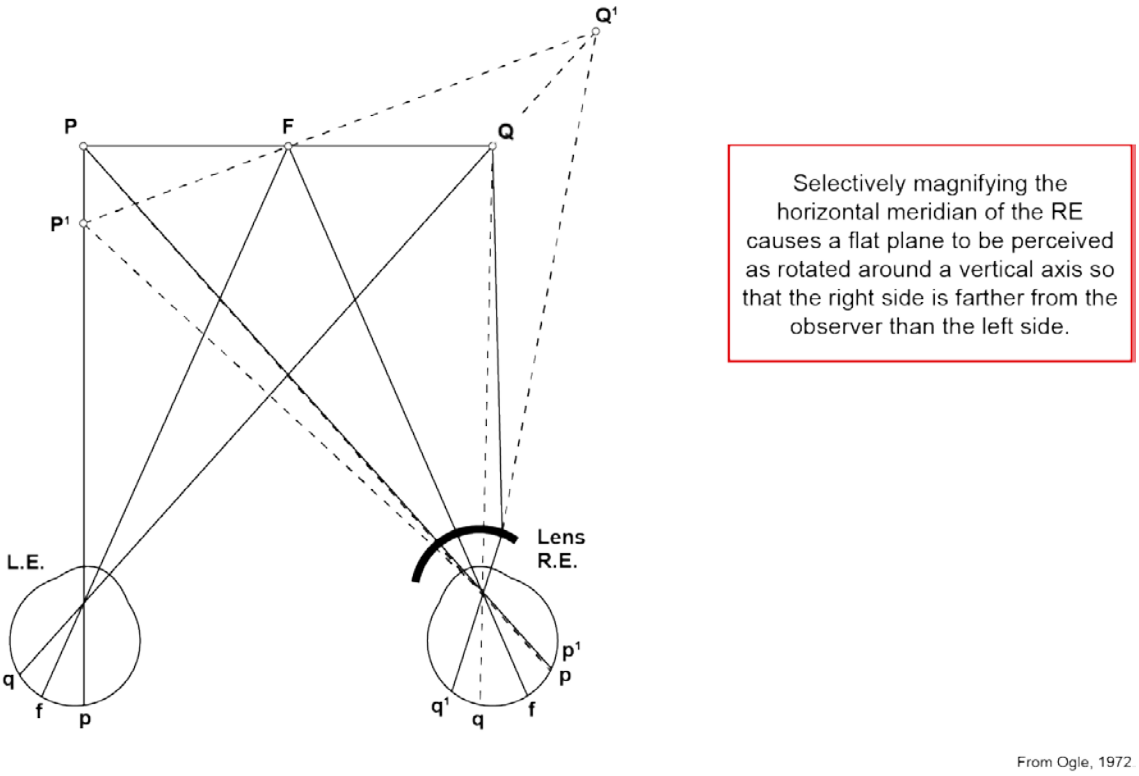


Figure 7.11: *Impact of selectively magnifying the horizontal meridian of the right eye using spectacle lenses (inspired by K N Ogle. Optics.Springfileld, Illinois,1972)*

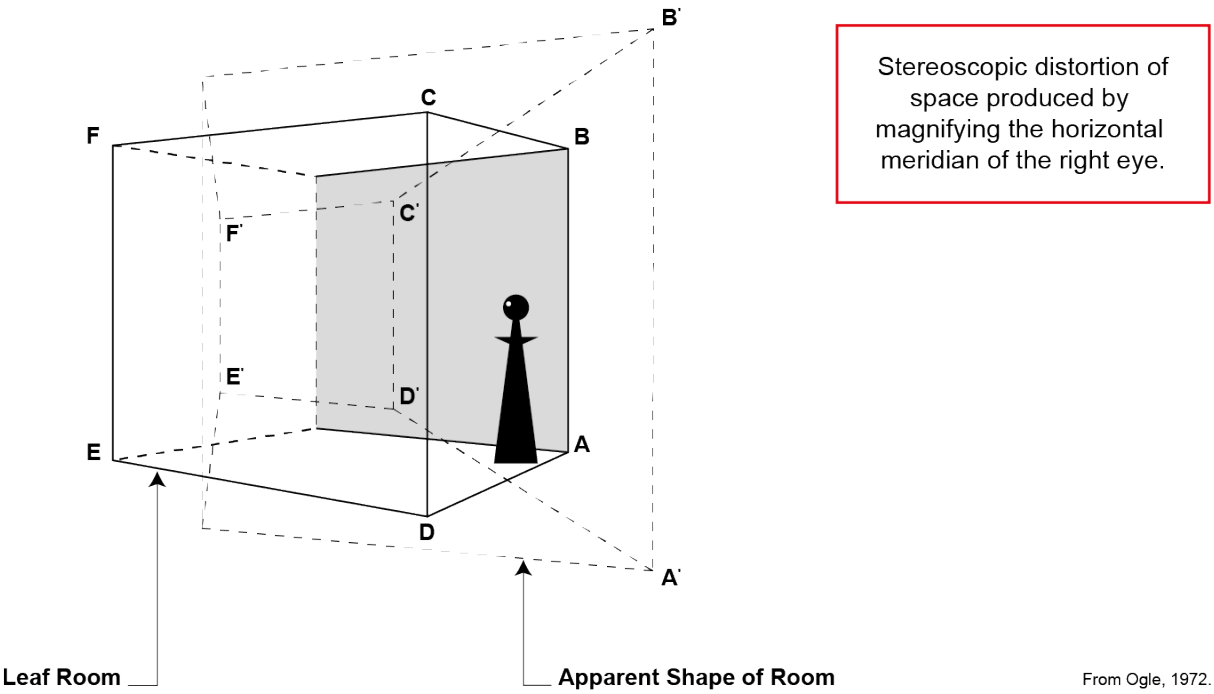


Figure 7.12: *Stereoscopic distortion of space by magnification in the horizontal meridian of the right eye (inspired by K N Ogle. Optics.Springfileld, Illinois,1972)*

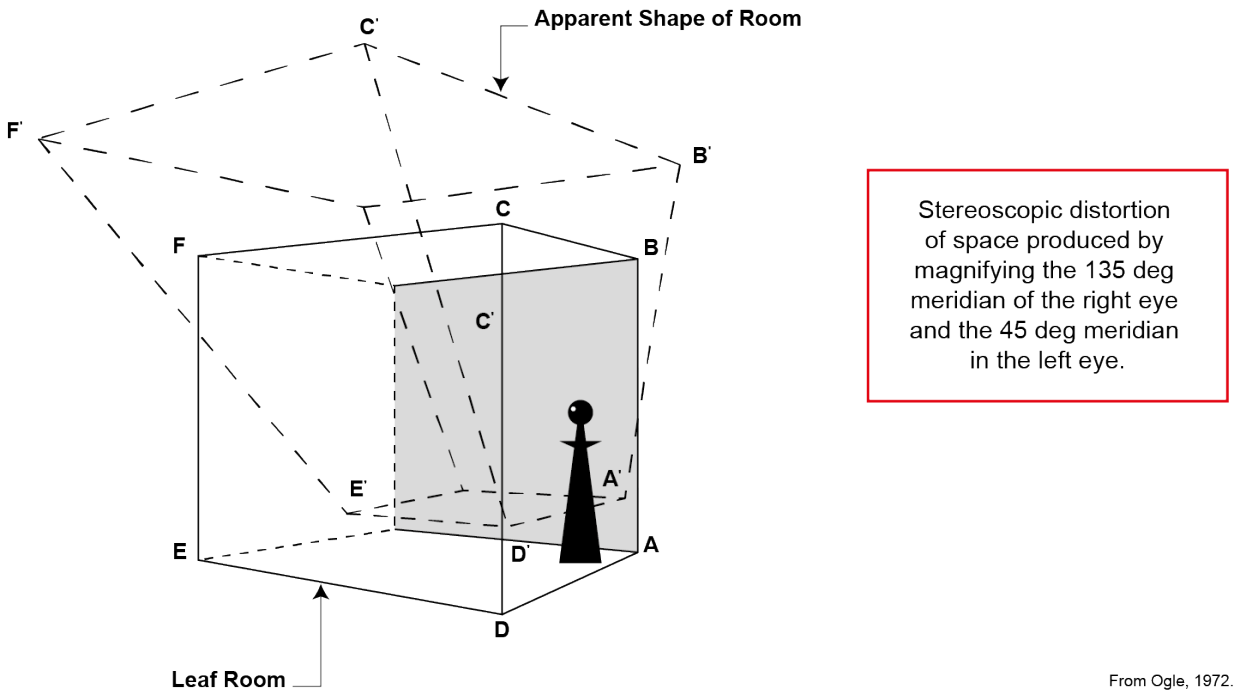


Figure 7.13: *Stereoscopic distortion of space by magnification in the oblique meridians of both eyes (inspired by K N Ogle. Optics.Springfileld, Illinois,1972)*

OCULAR ACCOMMODATION IN CORRECTED ASTIGMATS

As discussed in Chapter 4, spectacle lenses can have a substantial effect on ocular accommodative demands. The effects of correcting lenses on ocular accommodation depend on the position of the lens and the power of the lens. Since the power of cylinder lenses vary in each meridian, astigmatic individuals corrected with spectacles are confronted with a difficult situation when they focus from distance to near. The following example illustrates these potential difficulties. Assume that the myopic individual (ocular Rx: -5.00/-5.00 × 180) used in the previous examples is corrected with spectacles placed 15 mm in front of the eye's principal plane (spectacle Rx: -5.41/-6.35 × 180). How much accommodation is required to focus from infinity to a point 10 cm in front of the spectacle plane (see Fig 7.14)?

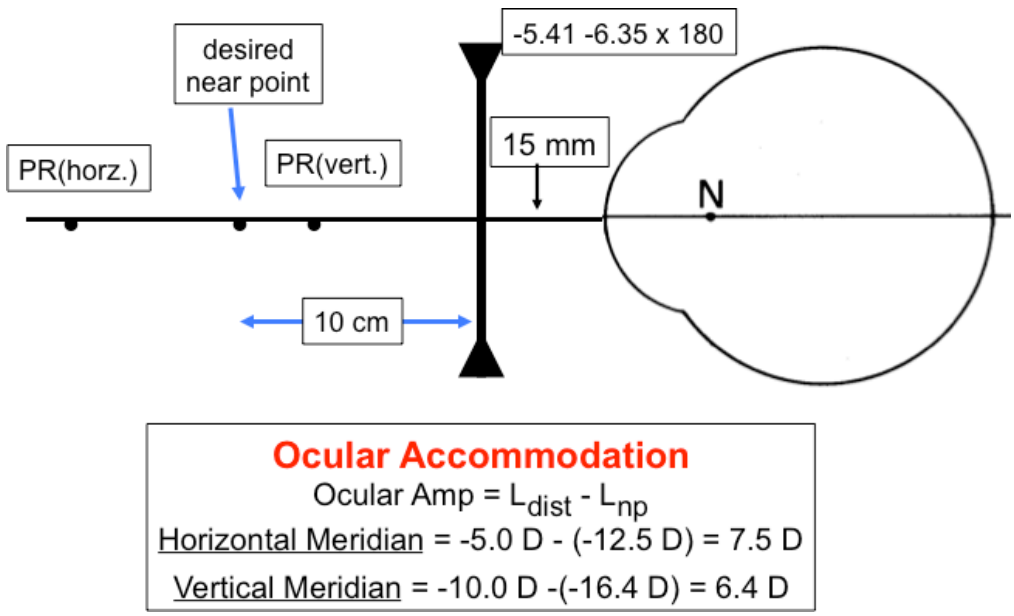


Figure 7.14: *Accommodation in astigmatic eyes corrected with spectacle lenses*

Since the vertical and horizontal meridians of the correcting lens have different powers they must be analyzed separately. In essence, it is like determining the accommodative demands for two different eyes.

SPECTACLE ACCOMMODATIVE DEMAND

The accommodative demand referenced with respect to the spectacle plane is the same for all meridians because spectacle accommodation is independent of the distance correcting lens. So for both the vertical and horizontal meridians, the spectacle accommodative demand for the point 10 cm in front of the spectacle plane is 10.00 D.

Ocular accommodative demand – Vertical meridian

As with spherical ametropias, to determine the ocular accommodative demand you must determine the change in the vergence of light at the eye's principal plane for an object at infinity and for an object 10 cm in front of the spectacle plane. And for both object points, the effects of the correcting lens must be taken into account. In this respect, it is necessary to determine the positions of the images of a distant and near object formed by refraction through the lens. The difference in vergence for these two positions measured with respect to the eye's principal plane will represent how much the eye's power must be increased to focus from optical infinity to the 10 cm point. But each principal meridian must be considered separately.

$F_{lens} = -11.76$ D

Distant object, vergence of light leaving the spectacle lens

$L' = L + F$
$L' = 0 - 11.76 \text{ D} = -11.76 \text{ D}$

Distant object, image position

$l' = n' / L'$
$l' = 1 / -11.76 \text{ D} = -0.085 \text{ m}$

Distant object, vergence of light at the eye's principal plane

$L_{fp} = n / l$
$L_{fp} = 1 / (-0.085 \text{ m} - 0.015 \text{ m})$
$L_{fp} = -10$ D

Near object, vergence of light leaving the spectacle lens

$L' = L + F$
$L' = -10.0 \text{ D} - 11.76 \text{ D} = -21.76 \text{ D}$

Near object, image position

$l' = n' / L'$
$l' = 1 / -21.76 \text{ D} = -0.046 \text{ m}$

Near object, vergence of light at the eye's principal plane

$L_{np} = n / l$
$L_{np} = 1 / (-0.046 \text{ m} - 0.015 \text{ m})$
$L_{np} = -16.4 \text{ D}$

The ocular accommodative demand for the vertical meridian is the difference between L_{np} and L_{fp}.

accommodative demand = −10.0 D − (−16.4 D) = 6.4 D

Viewing through the spectacle lens, the eye must accommodate 6.4 D in the vertical meridian to focus from infinity to the point 10 cm in front of the spectacle lens.

Ocular accommodative demand – Horizontal meridian

$F_{lens} = -5.41 \text{ D}$

Distant object, vergence of light leaving the spectacle lens

$L' = L + F$
$L' = 0 - 5.41 \text{ D} = -5.41\text{D}$

Distant object, image position

$l' = n' / L'$
$l' = 1 / -5.41 \text{ D} = -0.185 \text{ m}$

Distant object, vergence of light at the eye's principal plane

$L_{fp} = n / l$
$L_{fp} = 1 / (-0.185 \text{ m} - 0.015 \text{ m})$
$L_{fp} = -5.0 \text{ D}$

Near object, vergence of light leaving the spectacle lens

$L' = L + F$
$L' = -10.0 \text{ D} - 5.41 \text{ D} = -15.41 \text{ D}$

Near object, image position

$l' = n' / L'$
$l' = 1 / -15.41 \text{ D} = -0.065 \text{ m}$

Near object, vergence of light at the eye' principal plane

$L_{np} = n / l$
$L_{np} = 1 / (-0.065 \text{ m} - 0.015 \text{ m})$
$L_{np} = -12.5 \text{ D}$

Ocular accommodative demand

$$L_{fp} - L_{np} = -5.0\ D - (-12.5\ D) = 7.5\ D$$

Viewing through the spectacle lens, the power of the horizontal meridian of the eye must be increased 7.5 D to focus from infinity to a near object located 10 cm in front of the spectacle plane.

Based on the above calculations, this patient would have to accommodate 6.4 D and 7.5 D in the vertical and horizontal meridians, respectively, in order to focus on the near object. Since the increase in power associated with accommodating from distance to near is spherical (i.e. the power increases in all meridians by the same amount), it will not be possible to obtain a clear retinal image. Instead the image will be degraded by what amounts to an uncorrected astigmatic refractive error equivalent in magnitude to the difference in ocular accommodative demands for the principal meridians. Most textbooks suggest that in this situation the patient would accommodate by about 6.95 D so that the circle of least confusion would be located on the retina. However, relatively recent research suggests that the eye would probably accommodate for the vertical meridian or 6.4 D. It appears that the eye accommodates for the line focus which is closest to the retina and requires the least amount of effort. In this case, the horizontal meridian would be out of focus by about 1.1 D.

You may on occasion have an astigmatic patient that experiences problems associated with the different accommodative demands produced by spectacle corrections. Typically these patients will have relatively high cylindrical corrections, very close working demands, near visual demands that require very good spatial vision, e.g. small details, and they are very critical observers. The symptoms of the patient would be similar to those for an uncorrected astigmat. In these situations, there are a number of potential ways to solve the problem. If possible, the patient could be corrected with contact lenses. Contact lenses would virtually eliminate the problem because with contact lenses the ocular accommodative demands for near would be the same for all meridians. As an alternative, you could prescribe a second pair of single vision spectacles for near that have a cylinder correction which is different from that for distance vision. With this strategy you would have to determine the appropriate near astigmatic correction either by calculation or subjectively. Another approach would be to provide the individual with a plus add for both eyes for near. In essence, with this approach you are reducing the total accommodative demand for both meridians so that the interocular differences in ocular demand become small enough to be tolerated.

BIBLIOGRAPHY

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- K N Ogle. Optics.Springfileld, Illinois,1972.