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# PRISM: a help and a hindrance 

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"PRISMS ALWAYS PRODUCE AN OPTICAL ILLUSION, FOR THEY MAKE OBJECTS APPEAR IN A DIFFERENT POSITION FROM THAT WHICH THEY ACTUALLY OCCUPY," Ernest Maddox, The Clinical Use of Prisms; and the Decentering of Lenses 1889.

As an introduction to the topic of prismatic effects, it will be helpful to recall some of the basics. If light from a distant source in air meets a denser transparent medium normally, and the refracting surfaces are parallel as in a window (Figure 1a), there is no deviation - but light slows down, speeding up again on emerging into air. Where the surfaces are inclined to each other as in a prism, deviation will take place at one or both surfaces, depending on the angle of incidence, and the image formed displaced towards the apex (Figure 1b).

A Dutch mathematician and astronomer named Willebrord Snellius (thankfully contracted to Snell) put together a formula to show how light behaves when it reaches a medium of
different refractive index.
We have come to know this as Snell's Law: $n \sin i=n ' \sin i^{\prime}$ from which the expression $d=(n-1)$ a is derived and hence $P=100$ tan $d$. The change in direction of refracted rays is therefore dependent on the apical angle (a) and refractive index. This is usually recorded in prism dioptres $\Delta$, where one prism dioptre is the displacement of 1 cm at a distance of 100 cm .

The man with the fortuitous initials, CF Prentice, devised a rule linking centration, prismatic effect and power. He said that the prismatic effect at any point on a lens is the product of the distance of the point from the optical centre and the power in the same direction.

In Figure 2, c is the distance away from the optical centre and $F$ the power of the lens in this direction. The prismatic effect in prism dioptres $P$ is therefore $c \times F$. It must be remembered that $c$ is always in centimetres. If $c$ is zero, then the answer must be zero irrespective of lens power.


Figure 1a
Figure 1b

## FIGURE 1: Ray paths for parallel and inclined surfaces



## FIGURE 2: Power, centration and prismatic effect



FIGURE 3: Restoring binocular vision

For a spectacle lens, the optical centre is the point on the optical axis through which rays pass undeviated; so an optical centre can be defined as any point on a spectacle lens where there is no prismatic effect.

It follows from this definition that there must be some prismatic effect at any point, other than the optical centre. A prismatic effect will cause incident light to deviate from its original path, a factor which is not required unless the prescription includes a prismatic element. Positioning the optical centre should be relatively easy to achieve on a single vision lens, but becomes more problematic when we consider multifocals where there may be three optical centres to consider: $\mathrm{O}_{\mathrm{D}}$ for distance, $\mathrm{O}_{\mathrm{s}}$ for the segment considered as a separate lens, and $\mathrm{O}_{\mathrm{N}}-$ the near portion.

PRISMS (THE HELPFUL KIND) Ideally, we should be able to maintain binocular single vision with bifoveolar fixation and normal stereopsis; two clear retinal images should be formed of an object at any reasonable distance without undue pressures being put on the accommodation mechanism or the extrinsic ocular muscle balance.

Binocular single vision is conveniently checked by a cover test. With both eyes fixating an object, a cover is placed over one eye. The covered eye is now said to be in the passive position. If the eye maintains the same position when covered, then no movement of the eye will be observed when the cover is removed. This situation is called orthophoria.

However, if there is obvious movement of the eye as it is uncovered

| TYPE OF | PASSIVE POSITION |  |
| :---: | :---: | :---: |
| UNDER COVER | PRISM BASE |  |
| Exophoria | Outwards | In |
| Esophoria | Inwards | Out |
| Right hyperphoria | Right upwards | Down right or up left |
| Left hyperphoria | Left upwards | Down left or up right |

TABLE 1: Types of heterophoria and prism base direction

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and takes up fixation again (the active position) the condition known as heterophoria exists. Where heterophoria does not give rise to any symptoms it is said to be compensated; fine tuning of the extrinsic ocular muscle balance remedies the problem, but if symptoms do occur the heterophoria is uncompensated and may require remedial assistance in the form of prisms.

Figure 3 illustrates how binocular fixation can be restored using a suitable prism. The divergent left eye with uncompensated heterophoria fails to fixate on the same object as the right, so a base in prism is used to re-align the visual axis.

Prisms are orientated by means of their base. To relieve symptoms of heterophoria, the base will be placed over the weak muscle, so for example in exophoria where an eye has a tendency to move outwards, the medial rectus is the weak muscle and the prism would be base in (Table 1).

To create a prismatic effect, it is necessary to move the optical centre away from the visual axis. Depending on the power of the prism required and the strength of the prescription, it may be possible to use decentration to achieve this - but if not, the lens must be specially worked. If a temporary prismatic effect is required, a Fresnel lens can be used, although, due to the manufacturing process and vinyl material, visual acuity may be compromised. Despite this drawback, Fresnel prisms can be useful in cases of peripheral field loss where they are shaped and attached over part of a spectacle lens to displace the image.


FIGURE 4: Prism thinning on progressive lenses

-5.00DS


Figure 5b
-5.00DS


Figure 5c

FIGURE 5: Basics of a bicentric lens

Conditions such as nystagmus can sometimes be managed by prescribing yoke prisms. These are prisms of the same power and base direction, which displace the image towards the apex equally for right and left eyes.

Another useful application of prismatic effects is in prism thinning. This technique is used mainly on progressive power lenses to equalise edge thickness. As the power increases towards the bottom of the lens and the radius of curvature becomes shorter, the upper edge will appear thicker than the lower edge.

Reducing the difference usually requires working a prism numerically about two thirds of the reading addition base down, effectively reducing base up prism. This is shown in Figure 4. Prism thinning can be checked at the prism reference point and must, of course, be the same for both lenses. The visual effect will be to displace the image upwards but by the same amount right and left. Thinning prism is worked in addition to any prescribed prism.

## PRISMS (THE HINDRANCE)

Prismatic effects result in the displacement of the image seen through a spectacle lens, which can be helpful if that is what is needed. However, if this effect is not desirable, prismatic effects must be eliminated, or at least kept reasonably under control.

An ideal situation would be where the distance visual point (DVP) coincides with the distance optical centre, and the near visual point (NVP) with the near optical centre. With single vision lenses, these criteria are not difficult to achieve either by decentration or by neutralising any
unwanted prismatic effect.
Figure 5a shows a -5.00DS in plano concave form for simplicity. The subject will not encounter any prismatic effect at the optical centre, $\mathrm{O}_{\mathrm{D}}$, but when they look down through the near visual point, assumed here to be 10 mm below $\mathrm{O}_{\mathrm{D}}$, there will be $5 \Delta$ base down, which will cause upward displacement of the image.

It would be possible to cement $5 \Delta$ prism base up over the lower part of the lens to neutralise this (Figure 5c), or to use the slab-off surfacing procedure to remove $5 \Delta$ base down (Figure 5b), which would result in a more cosmetically acceptable result. In both cases, an optical centre would result at NVP, creating a bicentric lens. This can be done to a pair of lenses to eliminate all unwanted prism at the NVP.

In practice, the subject may simply lower the head rather than the eyes, but it should be confirmed that this is an acceptable remedy for them. For cases of significant anisometropia and multifocal lenses, lowering the head is not an option so they present a more complex problem.

There are several factors that determine whether or not specially adapted bifocals are necessary in anisometropia:

- Has the patient previously worn standard bifocals successfully?
- Are the visual acuities similar?
- Is one image being suppressed?
- Will the patient be able to avoid diplopia over long periods?
- Has there been a change in prescription for only one eye?

It is all too easy to jump to conclusions.
Figure 6 shows the eyes rotating
downwards and converging to read
through the prescription RE-1.00DS and $\mathrm{LE}+1.00 \mathrm{DS}$. It is assumed that there are no initial symptoms of vertical diplopia. There will be $2 \Delta$ vertical differential prism to overcome, base up in the left eye, so a prism of $2 \Delta$ base down is placed in front of the reading area of the left eye (Figure 7) and the patient's response noted.

If by adding the compensating prism the response is: "That's more comfortable", then this suggests that the cortical images are aligned in a more satisfactory way and the prism should be included. If the subject reports no difference in comfort when the prism is removed then there is little point in providing compensation.

In the horizontal meridian, the prism induced at NVP in the right lens is base in and in the left lens, base out, so these cancel in this example. Applying Prentice's Rule, the value of $c$ (the amount of convergence of each eye in the spectacle plane) is not likely to be more than 3 mm so prism values will be small.

It would seem logical to categorise this as significant anisometropia as there is 2.00D difference in power, but significant to whom? It may well be that the subject is able to compensate for the vertical differential prism, especially over short periods, and if wearing single vision lenses will be able to adjust their head position to suit.

If we then introduce a reading addition and have this dispensed as bifocals, this flexibility is no longer available, but there may still be no symptoms attributable to vertical differential prism. If the subject has previously worn standard bifocals without any symptoms of hyperphoria, it is unlikely that prism compensation will be necessary.


FIGURE 6: Prismatic effects and anisometropia


FIGURE 7: A remedy for vertical differential prismatic effect

However, subjects with less than 1.00D of vertical differential prism may experience fatigue in maintaining binocular vision over lengthy periods. Adopting British Standards centration tolerances as physiological tolerances has been suggested, which would mean $0.25 \Delta$ vertically and $1 \Delta$ horizontally. Where the visual acuities differ by several lines, it must be assumed that the subject has grown to be reliant on the eye with better acuity, so that the other image is largely suppressed, thus avoiding diplopia. However, some subjects report visual difficulties even when acuities differ by five lines or more. Research over many years has shown that there is no rule that can be applied to determine who can or cannot tolerate vertical differential prism. It is safe to say that, taking into account the individual's fusional reserves, tolerance of vertical differential prism is largely subjective. It is then the dispensing optician's job to determine whether or not compensation is necessary.

## DISPENSING WITH PRISMS

As a general guide, it is reasonable to conclude that where $1 \Delta$ or more of vertical differential prism exists at the near visual point and multifocals are to be dispensed, it is best to explore the possibility of prism compensation. It should be noted that the purpose of the compensating prism is to remove the vertical differential prismatic effect, and not to create a near optical centre at the near visual point.

Prismatic effects certainly need to be considered as a priority when dispensing bifocals. As an example, take a +3.50DS with a +2.50D addition, dispensed as a downcurve 38 mm bifocal (Figure 8). The segment drop is 5 mm and the near visual point 10 mm below the distance optical centre with no inset. Applying Prentice's Rule, the vertical prismatic effect at the near visual point due to the distance prescription is $3.5 \Delta$ base up.

The prismatic effect due to the segment is $3.5 \Delta$ base down so the optical centre of the near portion is actually at the near visual point, which is exactly what we are trying to achieve, but this is
a special case. If we cannot place $O_{N}$ at NVP, they should be as close as possible to avoid unwanted prism. A flat or curved top segment will produce base up prism because Os will be above NVP so this criteria cannot be fulfilled for a hypermetrope, but may be more useful for a myope as Figure 9 illustrates.

In Figure 9, the distance prescription is -0.75 DS , the addition is +2.50 D , and the optical centre of the flat top segment 3 mm below the segment top. The criteria will be satisfied as $0.75 \Delta$ base down due to the distance portion will be neutralised by $0.75 \Delta$ base up in the segment. This, again, is a special case. A round segment will produce base down prism with $\mathrm{O}_{\mathrm{s}}$ below NVP, adding to the base down due to the distance portion.

From the centration viewpoint, a hypermetrope will benefit by having a downcurve segment and a myope, a flat or curved top. In practical dispensing there will, of course, be many other factors influencing segment choice. It is unlikely, for instance, that large round segments will feature as first choice because of image jump (see later).



FIGURE 9: Bifocals for the myope


There are several options to consider where it is decided that vertical anisometropia needs to be corrected and multifocals dispensed. Figure $\mathbf{1 0}$ shows five round segments of increasing diameter and the relative position of $\mathrm{O}_{\mathrm{s}}$ to the NVP. Taking NVP as 10 mm below $O_{D}$ and the segment drop as 4 mm , the value of $c$ in Prentice's Rule will be (radius -0.6 ) in cm. Table 2 gives the prismatic effect at NVP for each of the segment diameters with an addition of +2.50 DS .

As each diameter produces a different prismatic effect, it may be possible to use two segments of different sizes to eliminate - or at least reduce - any prismatic imbalance to within an individual's tolerance. Take as an example the prescription:

## RIGHT EYE -3.00DS/+0.50DC $\times 180$ LEFT EYE -3.00DS/+3.00DC $\times 180$ Add + 2.50DS

The vertical differential prism 10 mm below $\mathrm{O}_{\mathrm{D}}$ is $2.5 \Delta$ base down RE. Two round segments are required, which produce a difference of $2.5 \Delta$ and from the table it can be seen that a 25 mm segment and a 45 mm segment would work. Another way of finding this information is to use the expression $d_{1}-d_{2}=(20 \mathrm{x}$ $\delta \Delta$ )/Add where $d_{1}-d_{2}$ is the difference in segment diameters. The answer here is $(20 \times 2.50) / 2.50=20 \mathrm{~mm}$. The larger of the two segments goes in the most hypermetropic (or least myopic) eye, so here, the left.

As with most dispensing options, there are limitations as well as benefits and a diameter difference of 25 mm or more would render this method impractical due to the availability of standard segment diameters. There are
also the factors of cosmetic appearance and the differences in visual fields to address.

## MANAGING UNWANTED EFFECTS

Another popular method is to slab-off the lower portion of the right lens in the same way as for a single vision bicentric lens (see Figure 11). The diagram shows the separate elements that contribute to the prismatic effects. Other lens forms, such as centre controlled, prism controlled, Franklin split, Fresnel and cemented segments, could be used to control vertical differential prism - but their availability and limitations tend to outweigh their benefits.

It is possible to use the slab-off technique on a progressive power lens to reduce any prismatic imbalance at the near visual point. As with bifocals or bicentric single vision lenses, the faint horizontal line where the prismatic effect changes is hardly noticeable. The slab-off process is in addition to working any prescribed prism and prism thinning.

Another example of unwanted prism can occur at the dividing line of a bifocal. Unless the optical centre of the segment is at the line, there will be a vertical
prismatic effect due to the segment (in Prentice's Rule, $c$ is the distance from the line to the segment optical centre and $F$ is the addition). This undesirable effect is known as 'jump' because that's what the image appears to do as the eye rotates to look over the line. The effects are shown

## in Figure 12.

It is worth noting that jump has nothing whatever to do with the distance prescription. The visual effect of the upward displacement of the image is to produce an annular scotoma around the segment line. The greater the distance of the segment optical centre from the line, the greater the jump.

Additional factors arise where prismatic effects are concerned, one being transverse chromatic aberration. The amount of transverse chromatic aberration (TCA) produced by a lens is dependent on the Abbe number and the prismatic effect at any specified point on the lens.

TCA $=c \times F / V$ which becomes $P / V$ where $c$ is the distance of the point from the optical centre, $F$ is the power in the same direction, and $V$ is the Abbe number.

It is this aberration that is sometimes noticed by patients when changing to a

| CIRCLE COLOUR | DIAMETER |  | P = c $\times$ F |
| :---: | :---: | :---: | :---: |
| BLACK | 22 mm | $0.5 \times 2.50$ | $1.25 \Delta$ |
| RED | 25 mm | $0.65 \times 2.50$ | $1.625 \Delta$ |
| ORANGE | 30 mm | $0.9 \times 2.50$ | $2.25 \Delta$ |
| BLUE | 38 mm | $1.3 \times 2.50$ | $3.25 \Delta$ |
| GREEN | 45 mm | $1.65 \times 2.50$ | $4.125 \Delta$ |
| TABLE 2: Prismatic effect at NVP for different segment diameters with an addition of +2.50DS |  |  |  |



FIGURE 12: Prismatic effect at the segment line


FIGURE 13: Effect of decentration on edge thickness for a minus lens
higher index lens, in addition to the effects caused by prisms and it may cause some visual annoyance. The tolerance generally accepted for transverse chromatic aberration, measured in prism dioptres, is $+/-0.1 \Delta$. The base direction of the prismatic effect will determine the order in which dispersion may be noticed.

Another potential issue is the increase in thickness caused by the introduction of prisms by surfacing or decentration. Figure 13 shows the effect of decentring a right -5.00DS lens in order to create $3 \Delta$ base out. Assuming a refractive index of 1.50 , a centre thickness of 1.5 mm and a lens diameter of 50 mm , the edge thickness $e_{1}$ will be 4.68 mm . Decentring the lens 6 mm inwards gives $3 \Delta$ base out, a reduced nasal edge $e_{3}$ of 3.32 mm and an increased temporal edge $e_{2}$ of 6.43 mm , a consequence which needs to be kept in mind when dispensing.

Similarly, Figure 14 illustrates the problem where a +5.00D lens is decentred inwards, effectively creating $3 \Delta$ base in. If the refractive index is 1.50 , the diameter 50 mm and the edge thickness $\mathrm{e}_{1}$ is 2 mm , the centre thickness of the lens before decentring would be 5.17 mm .

Keeping the temporal edge thickness as $2 \mathrm{~mm}\left(\mathrm{e}_{2}\right)$ the inward decentration will require a larger uncut resulting in the thickness at the optical centre increasing to 6.93 mm and the nasal edge thickness $e_{3}$ to 5.11 mm . The lens will become thicker and heavier, be more difficult to secure in a frame, and make any adjustments to pads on arms virtually impossible.

All of the prescriptions that pass across the dispensing optician's desk need to be checked for either the reduction or induction of prismatic effects. Only by careful attention to centration and lens options can undesirable effects be avoided and a reasonable compromise found.

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## ANDREW JOHN CRIPPS has worked

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DOMAIN: Clinical Practice
7.1: Conduct an adequate dispensing consultation ensuring any relevant information is obtained when dispensing patients with anisometropia.
7.5: Provide effective patient care and treatments based on current good practice when dispensing and ensure all considerations of prism are appropriately managed.


FIGURE 14: Effect of decentration on edge thickness for a plus lens

