SPECTACLE LENSES IN PRESBYOPIA - PITFALLS IN BACK VERTEX POWER NOTATION

Professor Mo Jalie highlights the pitfalls in back vertex power notation

The convenience and ease of use of spectacles to correct presbyopia is undoubtedly the reason why they are the first choice of correction for the majority of people. There is surely a place for bifocal contact lenses for long-established contact lens wearers, but it is unlikely that opticians will ask non-contact lens wearers, now in need of their first pair of readers, whether they would like the correction made up as contact lenses or spectacles.

However, spectacle lenses for near vision are not all they seem to be. They have their own advantages and disadvantages and this paper discusses some little known facts about the performance of spectacle lenses in near vision.

Spectacle lenses, whether prescribed for distance or near vision, are numbered in terms of their back vertex powers, but this system is really an unsound one when dealing with near vision.

Back vertex power is the vergence of the refracted pencil leaving the back surface of the lens when the vergence incident upon the front surface is zero. The light is assumed to be arriving from a distant object. In near vision we are not dealing with a distant object and the back vertex power system of numbering both the trial lenses and the final lenses provides only an approximate indication of the effect of the lenses. Consequently, it only provides an estimate of the real effect of the lens upon the eye.

Furthermore, the back vertex power value gives no indication of the peculiar gain in plus power which some lenses exhibit when the eye rotates away from the optical axis to view through peripheral portions of the lens. In these zones, the aberrations provide an artificial reading addition, which myopes in particular learn to use to their advantage to stave off a visit to their optician for their first pair of reading spectacles.

Let me explain these comments with some examples.

Consider an infinitely thin +10.00 D lens used for near vision at 1/3 metre. The vergence leaving the lens on the basis of the simple paraxial relationship is + 7.00 D. Now in reality a +10.00 lens is not infinitely thin, and the true vergence leaving the lens must depend upon the form and thickness of the lens **(Figure 1)**.

Suppose at first that the +10.00 lens is actually a trial lens of the type most commonly found in this country, a reduced aperture, plano-convex form, where the convex surface is designed to face the eye **(Figure 2a)**. Assigning a typical thickness to the trial lens and tracing a paraxial pencil of light from the near point through the lens, we find that the vergence in the refracted pencil which leaves the back surface of the trial lens is actually +7.02 D. The difference between this value and the anticipated value, on the basis of thin lens theory, +7.00 D, is termed the 'error' due to near vision effectivity, NVEE. In the case of the trial lens, the NVEE is the very small value, +0.02 D.

Suppose now that the near vision prescription, +10.00 D, is made up as a final lens with a back surface power of -3.00 D **(Figure 2b)**. Tracing a ray of light from the near point at 1/3 metre through each surface of this lens, we find that the vergence leaving the back surface is only +6.58 D, almost 0.50 dioptres less than the vergence leaving the trial lens[2]! In order to compensate for this loss of power, the wearer would have to move the reading material away from the eyes, or exert an extra amount of accommodation (if there is any!).

This is the source of the rule that in cases of aphakia, the reading addition must be increased by 0.50 or 0.75 D in order that the final lens may have the same effect as the trial lens.

This example is based upon paraxial theory. What happens when the eye rotates away from the optical axis, downwards and inwards, in the case of near vision?

The answer depends upon the form of the lens and the nature of the aberrations, which the eye encounters in the peripheral portions of the lens.

The present generation of dispensing students is fortunate in that, at the touch of a button, a computer will give them a full printout of the off-axis performance of any lens, which they specify. What does the computer inform them about the off-axis performance in near vision?

Suppose the eye rotates 25 degrees from the optical axis to view through a point which lies about 12mm down and in from the optical centre of the +10.00 D lens. The vergence in the pencil is +6.62/+0.37. This zone of the lens suffers from aberrational astigmatism **(Figure 3)**.

The oblique vergence is measured from the vertex sphere, an imaginary reference surface concentric with the eye's centre of rotation and just touching the back vertex of the lens. The vergences are referred to as the oblique vertex sphere image vergences. In the plane of rotation, the tangential oblique vertex sphere image vergence is +6.99 D and the sagittal value at right angles to this has become +6.62 D.

How can we now estimate the effect of the lens? If we consider the average value of the oblique vergence we can compare the position of that part of the refracted pencil where the cross-section is at its narrowest, the position of the disc of least confusion, with the paraxial focus. The average value of the vergence in the refracted pencil is called the mean oblique image vergence, MOIV, which in the case depicted is +6.81 D. Since the paraxial value is +6.58 D, the aberrations have added nearly a quarter of a dioptre of plus power as the eye has rotated away from the optical axis. As we might expect, the further the eye rotates, the greater this artificial reading addition becomes **(Figure 4)**.

Myopes benefit much more than hypermetropes from this gain in MOIV. In the case of a -5.00 D lens used for near vision at 1/3 metre, the reduction in accommodative demand is seen to reach 1.00 dioptre for a 35 degree rotation of the eye **(Figure 5)**. Should the -5.00 D lens be made in one of today's flatter forms, say with a +2.50 D outside curve, it will exhibit virtually no aberrational astigmatism for near vision. This single vision lens would perform like a theoretically perfect progressive power lens providing an addition of +1.00 D at about 17mm from the optical centre of the lens!

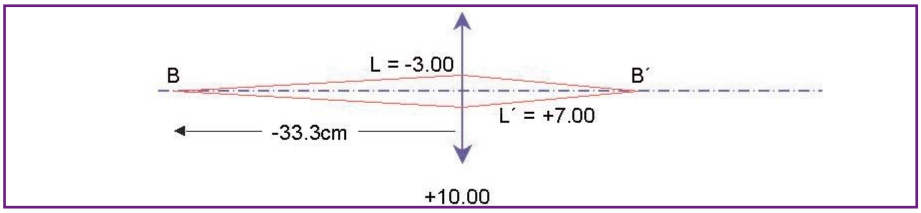
Sadly, you would not be able to sell it as such, because an ordinary focimeter would not detect this off-axis effect. A standard focimeter can only measure vertex power and does not ordinarily indicate the effect that the lens has on the eye viewing through the lens in near vision. However, a scanning focimeter can measure the off- axis oblique vertex sphere image vergence, when it is set up to demonstrate the effects of lenses in near vision.

This is a classic example of the aberrations of a spectacle lens acting as a friend to the wearer, rather than the foe that they are usually considered to be. This effect, or rather the loss of it, is the real reason why early presbyopes who are myopic and who exchange their spectacles for contact lenses as they approach presbyopia, have so much difficulty with contact lenses in near vision.

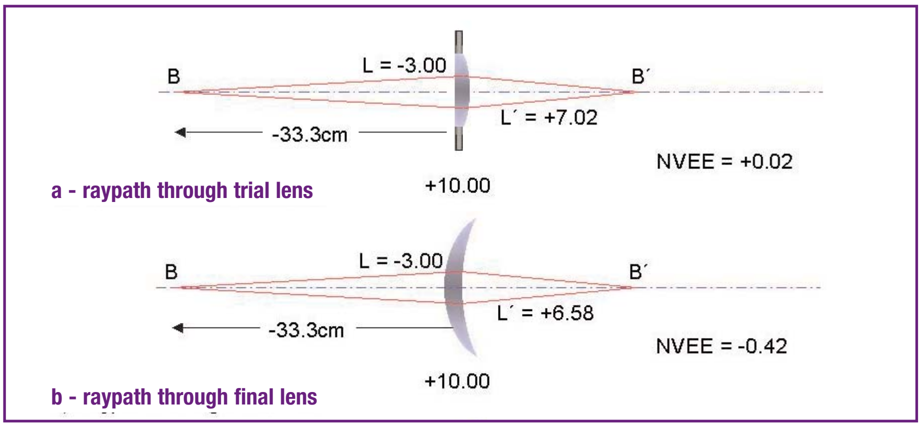
It is not just the convergence relief which the base in prism of their spectacle lenses provides, nor the 0.50 reduction in accommodative demand which they enjoy from the forward position of their spectacle correction. It is the removal of the artificial reading addition, which their spectacles provide, that myopes really complain of!

These effects become even more interesting in the case of bifocal lenses where it is quite easy to demonstrate the inadequacy of the focimeter in trying to determine the reading addition.

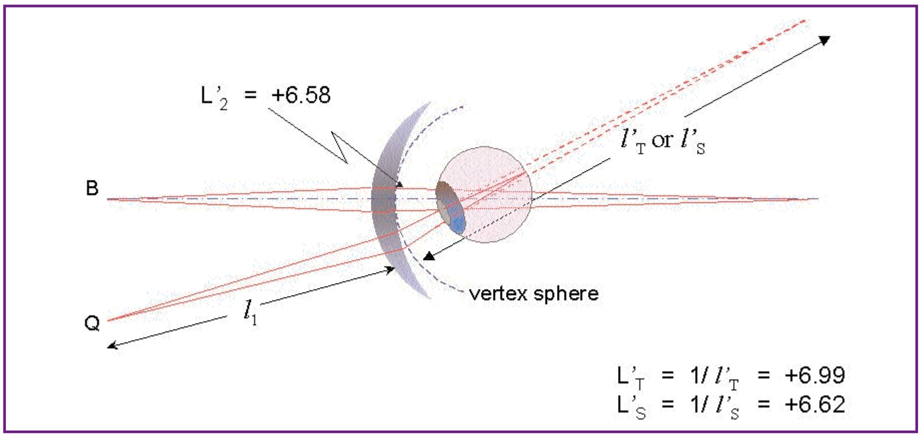
BS 2738, Measurement of Spectacles, defines the reading addition of a bifocal as the difference between the vertex powers of the near portion and the distance portion measured from the surface which contains the segment. This means, of course, that when the segment



▲ Figure 1: Paraxial equation applied to a thin lens

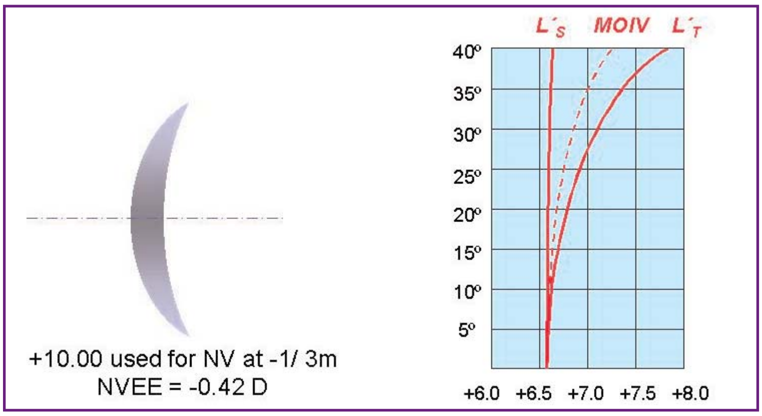


▲ Figure 2: Near vision effectivity error

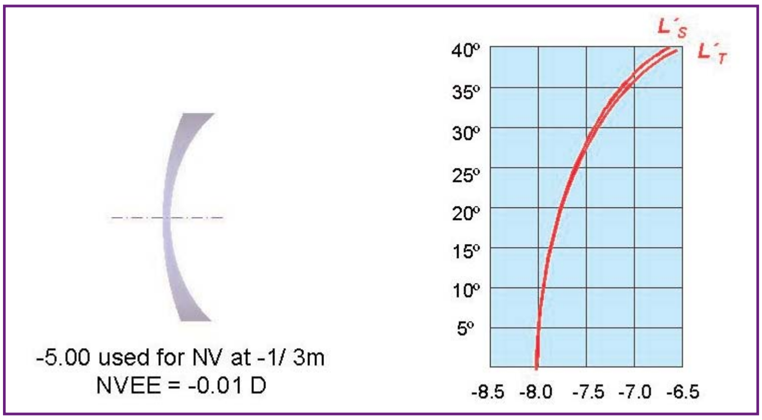


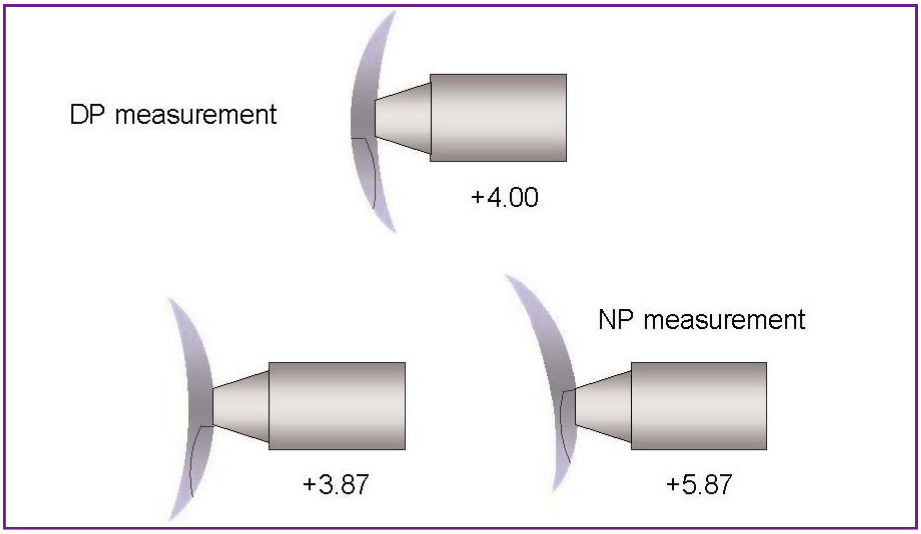
▲ Figure 3: Oblique vertex sphere image vergence

▶ Figure 4: Zonal variation of oblique vertex sphere image vergence for +10.00 D lens

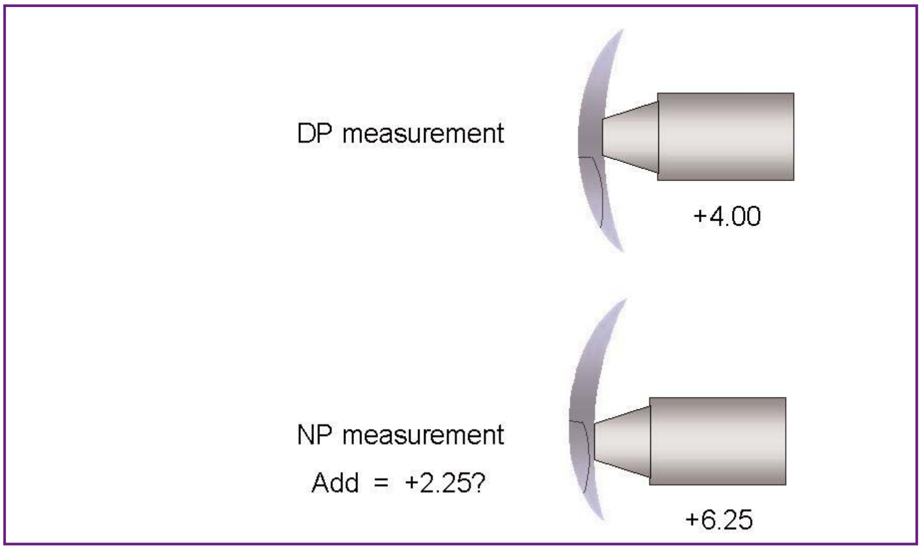


▶ Figure 5: Zonal variation of oblique vertex sphere image vergence for -5.00 D lens

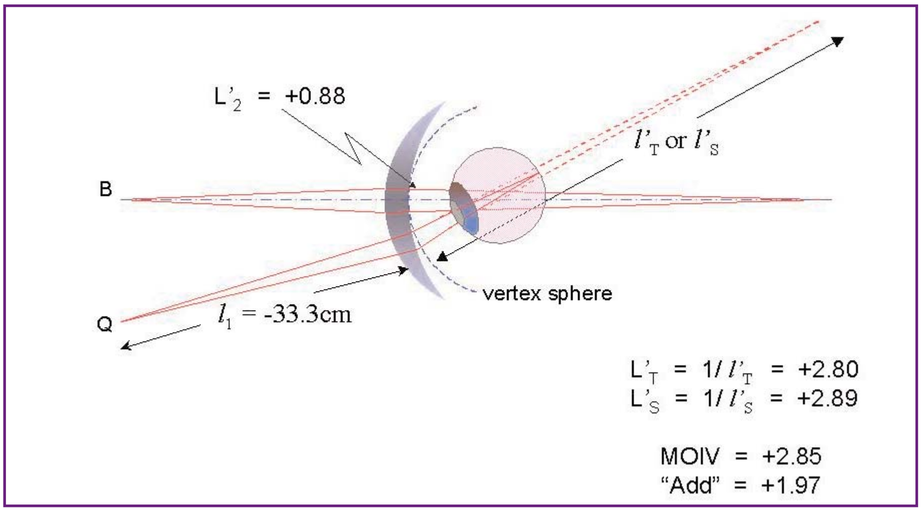




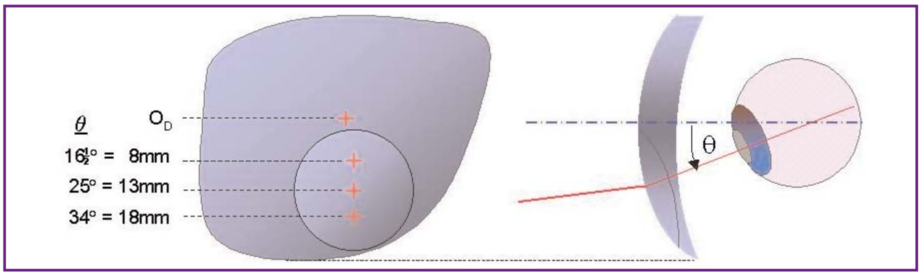
▲ **Figure 6: Measurement of near addition**



▲ **Figure 7: Incorrect measurement of near addition**



▲ **Figure 8: Real effect of +4.00 Add +2.00 bifocal used for near vision at -1/3m**



▲ **Figure 9: Position of visual points for various values of ocular rotation, θ**

is situated on the front surface of the lens, we have to turn the bifocal back to front in order to measure the reading addition **(Figure 6)**.

Take the case of a + 4.00 Add 2.00 bifocal where the segment has been fused to the front surface of the lens. If the lens is correctly made we would expect readings from the focimeter to be those indicated in **Figure 6**. The difference between the front vertex powers of the reading portion and the distance portion gives us the reading addition.

If we were to measure the back vertex power of the reading portion, we would obtain a reading of about +6.25 **(Figure 7)**. But it would be a mistake to assume that the reading addition is +2.25 D. Once again, the focimeter does not indicate the effect that the lens has upon the eye in near vision.

In order to determine the real effect upon the eye we must, once more, interrogate the computer. An accurate trigonometrical ray trace through the three surface element which represents the reading portion, tells us that the vergence leaving the RP is +2.80 with a +0.09 D cylinder **(Figure 8)**. The mean oblique image vergence in the refracted pencil, which is the value from which we can assess the real addition, is +2.85, and, comparing this with the vergence which leaves the distance portion, we find that the real addition which this segment provides is +1.97, a little less than the difference between the front vertex powers of the RP and DP.

You will appreciate that this value of the addition is for one zone of the segment only. The zone happens to be the geometrical centre of a 24mm diameter segment which has a drop of 1mm, so it is the zone 13mm below the distance optical centre **(Figure 9)**. What happens in other zones of the segment?

The graphs illustrated in **Figure 10** represent the variation in reading addition and the variation in oblique astigmatism as the eye sweeps downwards from a point near the top of the segment to a point near the bottom. The distance power is plotted horizontally above the graphs and the variation in reading addition and the value of the aberrational astigmatism is plotted to the same scale below the graphs. In an ideal bifocal design the appearance of the graph for each reading addition should be a vertical line coinciding with the power co-ordinate. This almost occurs for a +2.00 Add in the case of this bifocal design whose distance prescription is +4.00. In the case of a +3.00 Add, however, we can see that the error in the addition and in the astigmatism is small near the top of the segment, but that the addition begins to increase, and the astigmatism increases rapidly as the eye sweeps down through the segment.

Figure 11 illustrates the poor performance of a -6.00 D bifocal made with flat-top fused segments, firstly on the front surface (above) and then on the back surface (below). In the case of the Add 2.00 design with the segment on the convex surface, the addition near the bottom of the segment is about +2.87 D! When the segment is on the concave surface, the real addition near the bottom of the segment is about +2.50 D. Note in each case how the aberrational astigmatism increases at a similar rate to the near addition as the eye rotates down through the segment.

What happens when we compare different types of bifocal designs, in this case, solid bifocals where the segment is located either on the front surface or on the back? **(Figure 12)**.

Consider the prescription -6.00 Add 2.00. Firstly, we notice that, just like single vision minus lenses, we obtain a gain in mean oblique image vergence, the effect of which is to cause an increase in reading addition. Secondly, we can see that the increase in mean oblique image vergence is accompanied, in the case of this bifocal design, by an increase in aberrational astigmatism. If we want the optimum optical performance from the reading portion we need a relatively stable reading addition. When the -6.00 Add 2.00 is dispensed with the segment located on the front surface, the addition at the centre of the segment is actually +2.50, whereas when dispensed with the segment on the back surface the addition drops to +2.25.

We've heard it all before from our patients. "I don't care what your power checking instrument tells you, this new pair of plastics bifocals which you have made for me is different from my old glass pair!"

Have you spotted the obvious rule that will minimise this problem? It is generally true for all bifocal designs. Look carefully at **Figure 12**. In the case of a minus prescription, choose a bifocal design where the segment is situated on the back surface of the lens. You can see that both the error in reading addition and the aberrational astigmatism are much smaller for the minus power range when the segment is on the back. For plus prescriptions choose a bifocal design where the segment is situated on the front surface of the lens.

Useful formulae

1. Front surface power, F_1 is given by: $F_1 = F_{1N} / (1+(t/n) F_{1N})$ where F_{1N} is the nominal front surface power, t is the axial thickness in metres and n is the refractive index of the lens material.

2. Vergence leaving the lens in near vision, $L'_2 = (L_1 + F_1) / (1 - (t/n) (L_1 + F_1)) + F_2$ where L_1 is the vergence arriving at the lens from the near object, F_1 and F_2 are the front and back surface powers of the lens respectively and t and n have the same meanings as above.

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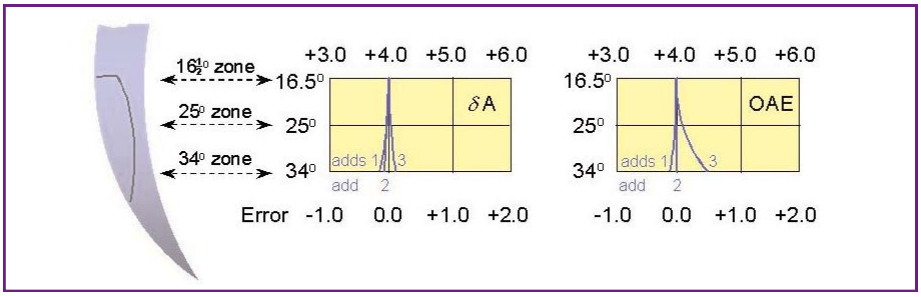
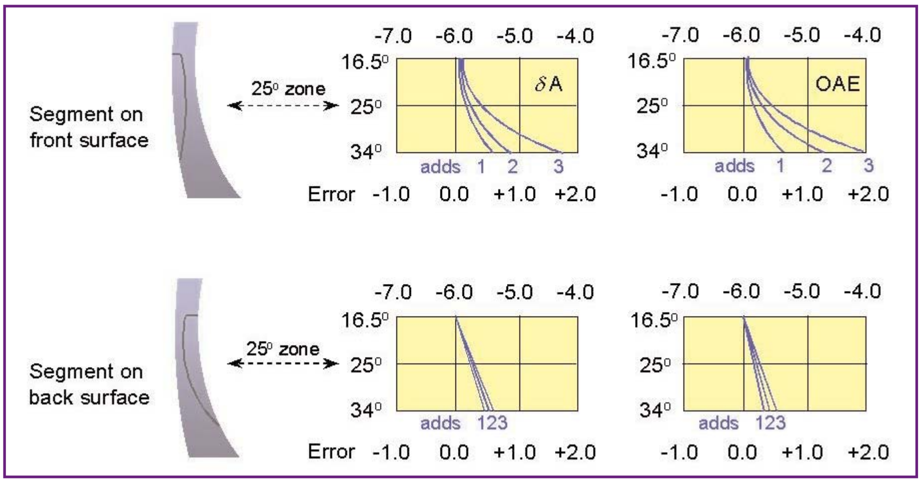
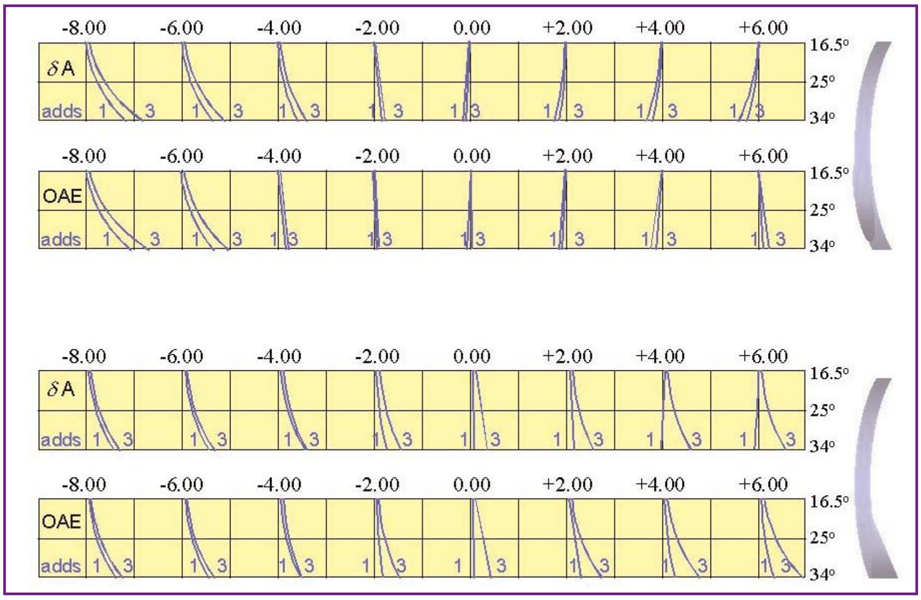


▲ Figure 10: Field diagram for near portion of flat-top bifocals, +4.00 Adds 1.00, 2.00 and 3.00



▲ Figure 11: Field diagram for near portion of flat-top bifocals, -6.00 Adds 1.00, 2.00 and 3.00



▲ Figure 12: Field diagram for near portion of solid bifocals, Rx -8.00 to+6.00 Adds 1.00, 2.00 and 3.00