

# REFRACTION: VERTEX DISTANCE MATTERS!


Although the effect of vertex distance on optical correction is well known, it is rarely taken into account in practice, except in cases of very strong corrections. When ophthalmic lenses were offered only in 0.25 D increments, this had little influence on most corrections. But today, with refraction determined in 0.01 D increments\* and the lenses associated with them, knowledge and measurement of vertex distance becomes particularly important. This article reviews the optical effects of vertex distance, shows how eye-to-phoropter distance can vary and discusses how vertex distance can now be taken into account for an accurate calculation of corrective lens power.



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The power of an optical correction for ametropia depends on the distance between the optical corrective system and the eye – this is one of the laws of physiological optics! Since the principle of optical correction is based on making the image focal point of the lens and the far point of the eye coincide, it is essential to adjust the system's focal distance – in other words, to modify its power – whenever the distance separating the corrective optical system from the eye is changed. For this reason, any value of an optical correction offered by a pair of eyeglasses depends on the vertex distance and every prescription should in theory be accompanied by the eye-to-phoropter distance it was established at. But in practice, this distance is rarely specified.

The importance of vertex distance is well known to those practitioners who prescribe contact lenses and must adjust the corrective power of these contact lenses in the plus powers direction from the correction for eyeglasses, most often with charts provided by the manufacturer. This is also the case in refractive surgery, in which the refraction is adjusted on the eye's optical plane .

As for eyeglasses, the optical effect depends on the correction power and is most often rather low ; it is generally not taken into account because it is lower than 0.25 D, the smallest power increment of traditional lenses. An exception to this is made for very strong corrections. It is estimated that a variation of 5 mm (+/- 2.5 mm) with a power of 5.00 D, inducing a variation of 0.125 D, is necessary to justify a change of correction by an increment of 0.25 D (see below). But now, with the new phoropters offering smooth power changes that make it possible to determine refraction in 0.01 D increments,\* it has become necessary to take into account this effect even for lower corrections. A same variation of 5 mm (+/- 2.5 mm) with a power of 2.00 D thus produces a variation of 0.02 D, which is significant enough to be incorporated into the lens power calculation.

\* The Vision-R 800 phoropter developed by Essilor Instruments.

\*\* For lenses with the Advanced Vision Accuracy (AVA) – manufactured in 0.01 D increments.

#### KEY WORDS:

Subjective refraction, phoropter, vertex distance, eye-to-phoropter distance, eye-to-frames distance, accurate lenses, Advanced Vision Accuracy, Vision-R 800.

In this article, we will first review the optical effects of vertex distance and then show, on the basis of measurements performed on a population of subjects, how much the distance between the phoropter and the eye can vary. Finally, we will address the practical implementation of this new vertex distance parameter for the new generation of lenses in increments of 0.01 D that are now available.

### A reminder of the optical effects of vertex distance

The basic optical principle behind the correction of any ametropia is to get the image focal point of the optical system, whether eyeglasses or contact lens, placed in coincidence with the far point of the eye being corrected. In this way, the corrective optical system, which creates optical images of distant objects on the lens's image focal point, projects them optically onto the far point of the eye which, as a result, sees them clearly in its disaccommodated state. This is how the ametropic eye achieves the optical situation of emmetropia.

From this basic principle, we can draw a simple conclusion: if the position of the corrective optical system is modified – in other words, if the distance between the lens and the eye is changed – its power must also be changed to ensure that the position of the image focal point  $F'$  coincides with the far point  $R$ , which does not change position because it is by nature “linked” to the eye (see Figure 1). Thus, if a lens is moved farther away from the eye, its power should be modified in the minus direction, and if it is moved closer it should be modified in the plus direction.

It should be noted that the optical effect of variation in vertex distance is produced “in the same direction” regardless of the power, positive or negative, of the correction. If the lens is moved farther away, there is always a positive power effect (that must be compensated for toward negative powers) and if it is moved closer, there is always a negative power effect (that must be compensated for toward positive powers).

Any patient with fully corrected vision who moves their lenses away from their eyes should theoretically notice their far vision become slightly blurred. But if they move their lenses closer to their eyes, they should not really notice any effects because they will compensate for the optical effect with their eyes' accommodation response. Similarly, any patient who moves their lenses farther away to read more comfortably is actually seeking a higher positive power or addition effect. In this regard, we could remember that patients with aphakia but without intra-ocular implants who wear corrective lenses with high positive power do manage to create significant near-vision addition simply by moving their lenses farther from their eyes. But these effects are only significant and noticeable for very strong corrections.

To objectify the optical effects of vertex distance, we must be able to quantify it. This can be done very easily in the following way: given  $R$ , the refraction of the eye to be corrected, otherwise known as the eye's refractive error or the proximity of the far point of the ametropic eye, the power DI of the lens correcting the ametropia can be expressed according to the vertex distance  $d$ , in the formula  $DI = R / (1 + d \times R)$ , with  $R$  measured in diopters and  $d$  in meters.

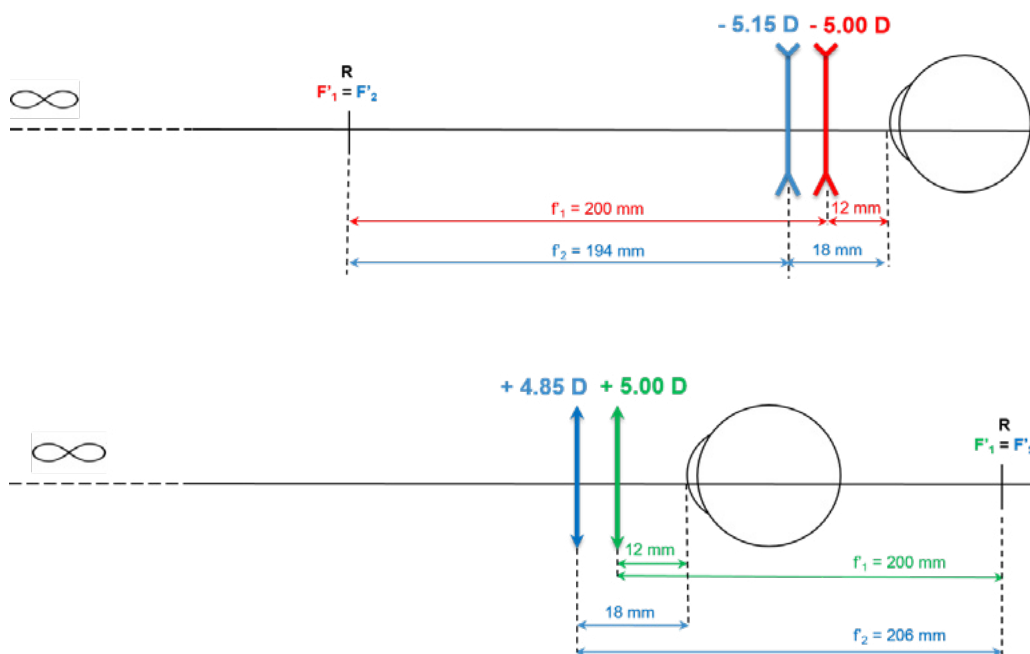


Figure 1: Necessary adjustment of refraction with modification of vertex distance :  
 a) A patient with myopia corrected by a  $-5.00$  D lens at a distance of  $12$  mm: the lens power must be adjusted to  $-5.15$  D if the vertex distance is increased by  $6$  mm.  
 b) A patient with hypermetropia corrected by a  $+5.00$  D lens at a distance of  $12$  mm: the lens power must be adjusted to  $+4.85$  D if the vertex distance is increased by  $6$  mm.

If the calculation is performed for all the correction powers and vertex distance variations, we can represent the effects using curves such as those in Figure 2. They show the vertex distance variations that are necessary to induce the respective power variations of 0.25 D, 0.125 D or 0.05 D, depending on the corrective power. We could, for example, determine from this that for a power of 5.00 D, a 5 mm (or +/- 2.5 mm) vertex distance induces a 0.125 D variation. We can then see the significant effects that vertex distance variations can have on optical correction.

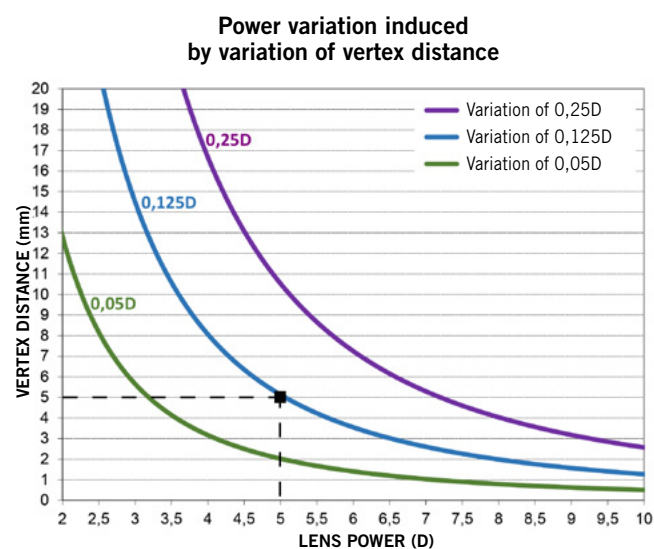


Figure 2: Power variations induced by variations of vertex distance as a function of lens corrective power

These curves also show that the optical effects are rather limited for most corrections. For this reason, not factoring in the vertex distance for ophthalmic lenses in 0.25 D increments has traditionally had only limited consequences, since the effect was less than the 0.25 D increment. It is therefore clear that for a range of corrections from -4.00 to +4.00 D in 0.25 D increments, not factoring in the vertex distance has never been particularly problematic but that beyond these powers, it was important to ensure that the correction took into account the distance at which the lenses would be worn. But now that lenses are available in 0.01 D increments, vertex distance matters even for low corrections, as we will see in the remainder of this article.

### Eye-to-phoropter distances can vary significantly!

To illustrate our point, a series of measurements of eye-to-phoropter distances for patients in refraction examinations was made. This was performed using a phoropter equipped with a system of video cameras designed to determine accurate measurements\* (Figure 3).

Eye-to-phoropter distance was measured in a sample of 50 patients selected at random. The phoropter position was adjusted for a reference patient at a distance of 12 mm with an adjustment to the forehead rest that was kept unchanged for the measurements performed on the remainder of the subjects.

Each measurement was taken as follows: the subject was placed behind the phoropter head, their gaze directed in the primary position, and was asked to look at a chart screen located 5 m away. The phoropter's interpupillary distance was adjusted for each eye. Using video cameras located behind each of the phoropter's half-heads, photos of each eye were taken laterally and appeared on the phoropter's control panel. Virtual reticle could then be adjusted and positioned in correspondence with the apex of each cornea. The adjustments were first made binocularly, and then if a difference was found between the left and right eyes, they were made monocularly. The system then indicated with great precision the value of the eye-to-phoropter distance in 0.5 mm increments. This measurement could be recorded. For each patient, the measurement was taken three times, the patients being asked to move back from the phoropter and then to reposition themselves.

In addition, 30 measurements were repeated on a patient of reference, asking him to move his head back from the phoropter after each measurement and reposition himself for each new measurement.

The results of these measurements are presented in Figure 4. On the one hand, they show that the eye-to-phoropter distance varied by 15.5 mm (from 4.0 mm for the smallest to 19.5 mm for the largest) with an average established at 11.1 mm with a standard deviation of +/- 3.11 mm – which is considerable. On the other hand, the measurements repeated on one patient show a range of variation of 5.0 mm with a standard deviation of +/- 1.31 mm, that is also significant. It is thus very clear that the distance between the eye and the phoropter is an eminently variable parameter and depends on the morphology of a patient's head as well as how the patient is positioned behind the phoropter. They show that the often-neglected parameter of eye-to-phoropter distance must absolutely be included in the calculation of a correction if it is to be accurate.

## Practical consideration of vertex distance

### Adjusting eye-to-phoropter distance

Although the importance of vertex distance is well known, it is not always taken into consideration. In practice, eye-to-phoropter distance is only rarely incorporated, much less measured, in a refraction examination. It is most often verified and adjusted when the phoropter is positioned in front of the patient's head so that it corresponds to an average value. The phoropter must be positioned close enough to the patient's eyes that they have as wide a field of vision as possible, but not so close that their eyelashes touch the phoropter's back window (which is not only unpleasant for the patient but can make the phoropter dirty). With traditional phoropters, this adjustment is achieved by adjusting the forehead rest, paying close attention to the patient's eyes, either from behind the phoropter or through the phoropter using a specially designed system of graduated lateral mirrors.



Figure 3: Measuring eye-to-phoropter distance by video camera

Several aspects related to eye-to-phoropter distance must be noted:

- It can vary considerably from one patient to another with the very same forehead rest position (as we have shown). For this reason, it is essential to carefully adjust the phoropter head in front of the patient's eyes.
- The patient's head position also influences this distance: it is reduced if the patient lifts their head up and increased if they lower it, so it is important for the patient to be in a comfortable enough position that they will not tend to change it during the refraction.
- The distance can furthermore change over the course of the refraction, so it is important to check it at the end of the examination, in particular for strong corrections and the prescribing of accurate lenses, in 0.01 D increments.

The eye-to-phoropter distance is a parameter that rarely receives enough attention. It can be verified with traditional phoropters but is difficult to measure it exactly. With modern phoropters,\* it is now possible to measure

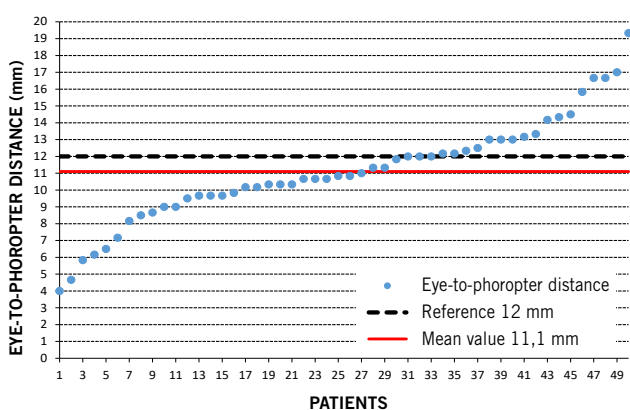
this distance accurately using video cameras and to adjust it with great precision so that it can be factored into the calculation of a lens correction.

### Measuring eye-to-frames distance

Although it is important to be able to accurately determine the eye-to-phoropter distance, knowing this distance will matter little if you cannot also measure the distance between the eye and the eyeglass frames. Opticians have various systems allowing them to measure this. In the past, some manual measurement devices were sometimes used, but today these measurements are performed with columns and electronic tablets. A review of these techniques is outside the scope of this article, but it is enough to mention that these systems most often operate on taking multiple images of the frames and the patient's eyes to reconstitute their relative positions in three dimensions and to accurately calculate the distance that separate the frame from the apex of the cornea of each eye. The eye-to-frame distance can thus be measured and then used to achieve an accurate calculation of the optical correction.

### Inter-patients variability of eye-to-phoropter distance measured on 50 patients

(with a forehead rest adjusted at 12 mm for a patient of reference)



### Intra-patient variability of eye-to-phoropter distance 30 measurements on one patient

(with a forehead rest adjusted at 12 mm for a patient of reference)

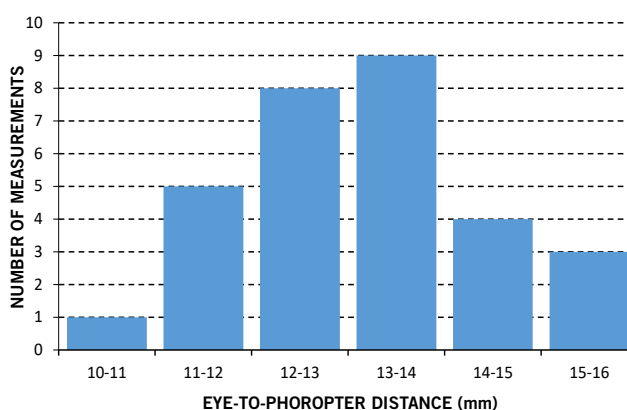


Figure 4: Variability in eye-to-phoropter in a population of patients.

- Inter-patients variability measured on 50 patients
- Intra-patient variability measured on one patient (30 measurements)

## ***Incorporating vertex distance into the calculation of lens correction in 0.01 D increments***

Vertex distance is a parameter that has never really been considered for the adjustment of optical corrections until now. It has always been assumed that the power of an optical correction is established for the distance at which the lenses will be worn. But in reality, this is rarely the case.

This hypothesis has also been used for “personalized” lenses for which data on the position of the eye behind the lens is measured and introduced into the lens calculation. In this case, it is more specifically the distance separating the eye’s centre of rotation (ERC) from the frame that is used to optimise the design of the optical surfaces of lenses with complex geometry, simulating the eye exploring the lens in this position. But it has also invariably been assumed that the optical prescription was established for the exact distance at which the lenses would be worn, in the primary direction of the gaze.

Today, thanks to new technology making it possible to easily and accurately measure eye-to-phoropter and eye-to-frame distances, we can now take into account the vertex distance into the calculation of lens corrections. This makes it essential to do so throughout the entire process, as follows:

- First, the eye-to-phoropter distance must be measured during the refraction examination. Then at the end of the examination, the value of the prescription must be converted, for the standard reference distance of 12 mm, the calculation being made automatically by the phoropter.\*
- Next, after the frames have been selected but before lenses are to be ordered, the optician must measure the eye-to-frame distance and provide this measurement to the manufacturer when ordering the lenses.\*\*
- Finally, the manufacturer must convert the value of the optical correction, considered to be established for 12 mm, for the real eye-to-frames distance measured by the optician, just before the lenses are manufactured.

In this way, the vertex distance is incorporated throughout the entire process and accuracy is maintained from the refraction examination to the delivery of the eyeglasses through the fitting measurements. If this is done, it is possible to provide patients with a highly accurate correction of their ametropia.

## **Conclusion:**

Thanks to improvements in refraction and measuring instruments, vertex distance is a parameter that can now be measured very accurately and thus be taken into account. It is becoming a complementary parameter of a prescription for proposing highly accurate lenses.\*\* All vision-care professionals now have the opportunity to offer their patients a more accurate correction and make them benefit from an even better vision.



### **KEY TAKES WAYS**

- The effect of vertex distance on optical correction is well known but rarely taken into account in practice, except in cases with very strong corrections. When ophthalmic lenses were offered only in 0.25 D increments, this had little influence on most corrections.
- But now that lenses are available in increments as small as 0.01 D, thanks to subjective phoropters with continuous power changes, and lenses can be manufactured in these increments as well, vertex distance matters even for low corrections.
- To factor vertex distance into a correction, the eye-care-practitioner must measure the eye-to-phoropter distance during the refraction exam and the eye-to-frame distance when adapting the eyeglasses. The optical correction can then be very precisely adjusted for the manufacture of lenses with exact correction power.
- Vertex distance is thus becoming a complementary refraction parameter enabling eye-care-practitioners to offer patients an even more accurate correction of their ametropia.

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