

The Varilux S Series™: 4D Technology™ — The Next Level of Personalization: The Leading Dominant Eye™

Mark A. Bullimore, MCOptom, PhD, FAAO • Kirk L. Smick, OD, FAAO

Three groundbreaking technologies underlie the extraordinary benefits of new Varilux S Series™ lenses:

- **Nanoptix Technology™:** A breakthrough technology that virtually eliminates “swim” compared to other premium progressive lenses. Nanoptix Technology™ reengineers the basic shape of the progressive lens by considering the lens as a set of many optical elements, allowing designers to minimize image deformation while maintaining the power progression.
- **SynchronEyes Technology™:** A powerful, innovative technology that integrates prescription data from both eyes into each lens, optimizing binocular visual fields and giving wearers expansive vision.
- **4D Technology™:** A revolution in lens personalization that enhances overall visual response times by ensuring the sharpest vision in the leading dominant eye™. (Available only on Varilux S 4D™ lenses.)

The focus of this paper will be on the means by which Nanoptix Technology™, SynchronEyes Technology™, and 4D Technology™ work together to virtually eliminate “swim” for stable vision, support binocularity of expansive vision, and sharpen vision in the leading dominant eye™ to speed visual reaction times.

SYNCHROEYES TECHNOLOGY™: THE REVOLUTION IN LENS DESIGN

Most people see with two eyes, which are located a short distance apart. The fields of vision from each eye overlap, so that an extensive portion of our visual field is observed simultaneously by both eyes from slightly different points of view. Each retina transmits its monocular image via the optic nerve to the visual cortex, which analyzes the neural signals and transforms them into a single three-dimensional perception of the world. This process of forming a single, clear perception from two slightly different images is binocular vision.

The Stages of Binocular Vision

Binocular vision is the result of a series of neural processes.¹ The first, *simultaneous perception*, allows the visual cortex to receive and analyze slightly different images from the two eyes without suppressing information from either eye. (If the images are too different, one will be suppressed, as is the case in amblyopia.)

The next step, *fusion*, allows the brain to integrate the two retinal images into a single perception. Good fusion enables the third step, *binocular summation*, which occurs when visual detection or discrimination with both eyes is better

than with the best eye alone. Studies show—and everyday experience confirms—improved acuity with binocular vision compared to monocular vision, especially in low-contrast situations.^{2,3}

The final step in binocular vision is *stereopsis*, in which the brain takes the two-dimensional images from each retina, analyzes them, and converts them into a three-dimensional picture of the world. Stereopsis helps provide accurate depth and distance perception.

Progressive Lenses and Binocular Vision

Studies show that the best stereopsis is achieved when the images from the left eye and the right eye are balanced with respect to size, shape, and aberrations. As we shall see, this is the situation needed for optimal binocular summation and depth perception.

Castro and coworkers demonstrated this in 2009, showing that binocular summation was optimized when the retinal images in each of a subject's two eyes were of equivalent optical quality.⁴ In their study, optical quality was determined using the Strehl ratio for each eye. (Based on the difference between a theoretical optimum point spread function and the measured point spread function, the Strehl ratio is a widely recognized indicator of optical quality.) Castro and

coworkers found a statistically significant correlation between binocular summation and the Strehl ratio of each eye—that is, binocular summation was best when the Strehl ratio of one eye matched the Strehl ratio of the fellow eye (Figure

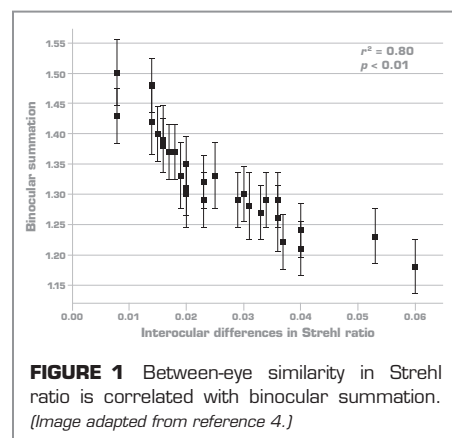


FIGURE 1 Between-eye similarity in Strehl ratio is correlated with binocular summation. (Image adapted from reference 4.)

1).

In a subsequent study, Castro and coworkers evaluated the effect of differences in retinal image quality on stereoscopic depth perception in 25 subjects ranging in age from 21 to 61 years.⁵ The results showed a significant inverse correlation between maximum tolerable binocular image disparity and between-eye differences in the Strehl ratio (Figure 2). In other words, the closer the

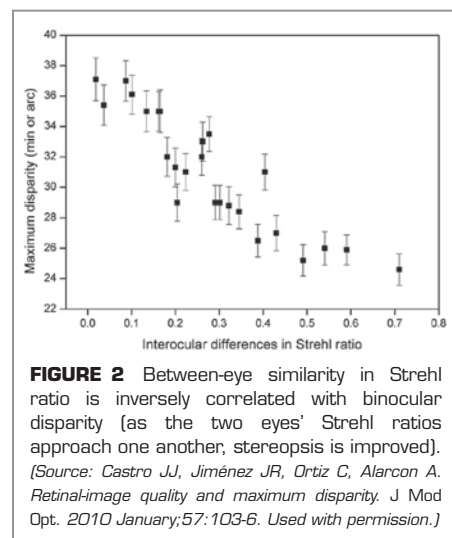


FIGURE 2 Between-eye similarity in Strehl ratio is inversely correlated with binocular disparity (as the two eyes' Strehl ratios approach one another, stereopsis is improved). (Source: Castro JJ, Jiménez JR, Ortiz C, Alarcon A. Retinal-image quality and maximum disparity. J Mod Opt. 2010 January;57:103-6. Used with permission.)

Strehl ratios, the greater the image disparity the brain could perceive. Greater binocular image disparity provides the visual system with more information about the spatial relations of the objects in view, so the ability to perceive larger degrees of image disparity supports better stereopsis and wider fields of clear vision.

All this is of importance to lens wearers because, until now, progressive lenses have all been optimized for each eye independently. But if right and left lenses are calculated without reference to one another, differences in image quality can easily result,

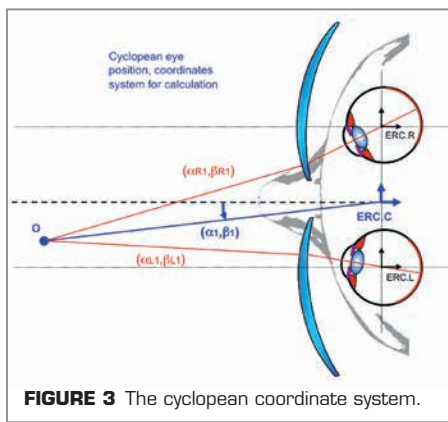


FIGURE 3 The cyclopean coordinate system.

producing problems in image fusion and depth perception—and ultimately, reducing binocular fields of vision.

Binocular Vision Management Before the Varilux S Series™

Over the years, various groups have claimed to be able to manage binocular vision in ophthalmic lenses, and these efforts have been of two types.

The first method involves the location of the near, intermediate, and distance zones to optimally meet the needs of convergence. These zones have to be centered along a line that represents the point at which the line of gaze intersects the lens when viewing at each distance. Specifically, the near vision zone has to be shifted nasally (inset) compared the distance zone, in order to take into account prismatic effects and convergence at near; this inset is calculated as a function of monocular pupillary distance.

The second means by which lens designers attempt to balance the vision in each eye involves the distribution of powers and aberrations across the lens. This is of importance when the wearer’s gaze shifts off-axis. Over the years, man-

ufacturers have claimed that various nasal/temporal design strategies could balance off-axis images, even in the case of astigmatic prescriptions.

While some of these strategies have helped, before the Varilux S Series™, all methods have been based on a *monocular* model that takes into account one eye at a time. Before the Varilux S Series™, all design models treated eyes as parallel but independent visual systems. This is adequate to ensure good performance in each eye, but it cannot guarantee the balance between right and left retinal images that, as we have shown, is needed to optimize *binocular* vision.

SynchronEyes Technology™: A Revolutionary Approach

With SynchronEyes Technology™, for the first time, the optical differences between the two eyes are incorporated into each lens design to create one visual system. Data from both eyes is required to order a single lens, and the optical design for one eye always takes into account the lens in front of the other eye.

The lens calculation with SynchronEyes Technology™ is made possible by three key computational elements. The first of these, the *cyclopean eye*, is a mathematical model named for the Cyclops of Greek mythology. This paradigm treats vision as if humans saw the world from a single cyclopean eye situated at the midpoint between the eye rotation centers of the two anatomical eyes.

The second element is a three-dimensional environment in which the distance of objects seen can be noted as a function of the gaze direction. This gives rise to the third element, a cyclopean coordinate system (Figure 3). In this coordinate system, for each object point O, the right-eye gaze direction and the left-eye gaze direction can each be mapped. The right-eye gaze intersects the right lens at a point on the lens that is said to “correspond” to the point on the left lens where it is intersected by the left-eye gaze.

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So for each binocular gaze direction there are corresponding points on the left and right lenses through which gaze travels. Once these points are known,

they can be optimized so that vision quality through each is essentially equivalent. This fulfills a basic requirement for optimized *binocular* vision.

We can see the process of creating a lens with SynchronEyes Technology™ as a three-step process (Figure 4):

- **Step 1:** Determination of the wearer’s prescription to build a unique binocular optical system.
- **Step 2:** Definition of a binocular optical design according to the wearer’s prescription, calculating the lenses as a pair.
- **Step 3:** Application of the optical design to both lenses, so that both eyes can work together as a visual system.

SynchronEyes Technology™ Benefits

To see its benefits, we can compare Varilux S Series™ lenses with SynchronEyes Technology™ to standard lenses (Figure 5). In the standard design, right and left lenses are calculated independently. When looking to the side, the wearer’s gaze crosses right and left lenses at zones with different optical properties. Right and left retinal images are therefore different in quality, resulting in binocular imbalance. This is perceived by the wearer

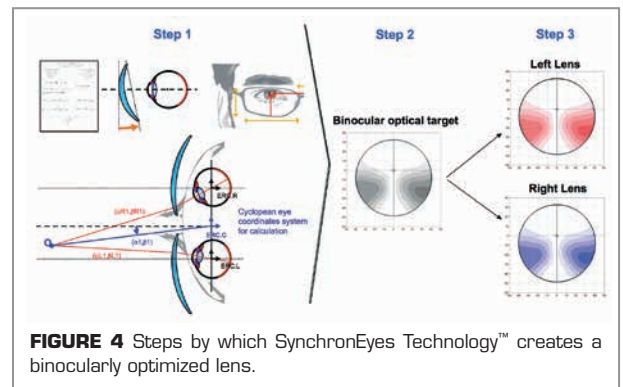


FIGURE 4 Steps by which SynchronEyes Technology™ creates a binocularly optimized lens.

as reduced fields of vision, and the effect worsens with increasing anisometropia.

By contrast, Varilux S Series™ lenses are synchronized by taking into account prescription differences between the two eyes. When looking in the periphery, the wearer’s gaze crosses right and left lenses at zones with similar optical performance. Right and left retinal images are therefore similar in quality, ensuring binocular balance. Wearers experience virtually unlimited and expansive vision, even when the prescriptions vary greatly between the two eyes.

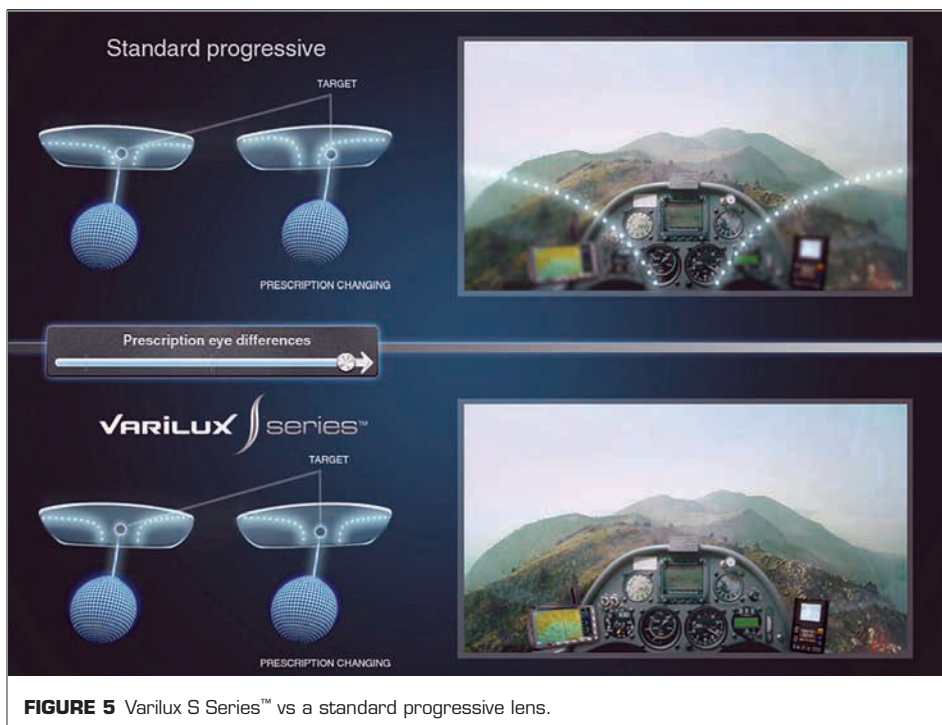


FIGURE 5 Varilux S Series™ vs a standard progressive lens.

This is an important development, as the vast majority of progressive lens wearers have differing prescriptions from eye to eye. A statistical analysis of 136,800 premium progressive lens wearer prescriptions in the US shows that 90% have some degree of anisometropia with regard to sphere or cylinder.

The benefits of SynchronEyes Technology™ have been demonstrated in the laboratory through objective measurements of visual zone widths. These measurements show that Varilux S Series™ lenses offer wider binocular fields of vision compared to Varilux Physio Enhanced™ and other premium lenses.

4D TECHNOLOGY™: THE REVOLUTION IN LENS PERSONALIZATION

The Leading Dominant Eye™

Just as most people are either right-handed or left-handed, most of us also have a dominant eye. The leading dominant eye™ is the eye that leads the other in perceptual and motor tasks.⁶ For example, when gaze shifts to a new target, it is the leading dominant eye™ that gets there first and leads the fellow eye.

This phenomenon was demonstrated by Kawata and Ohtsuka, who measured eye vergence movements in response to a moving visual stimulus centered between the two eyes.⁷ Their results suggest strong-

ly that the brain's ocular control system favors the leading dominant eye™ as the eye moves to track a target. Kawata and Ohtsuka's work showed that the leading dominant eye™ starts its movement to the target more quickly than the nondominant eye and reaches the target first.

Other work has shown that inputs from the leading dominant eye™ are preferentially processed in comparison to the complementary inputs from the nondominant eye. In particular, there is better target detection with the lead-

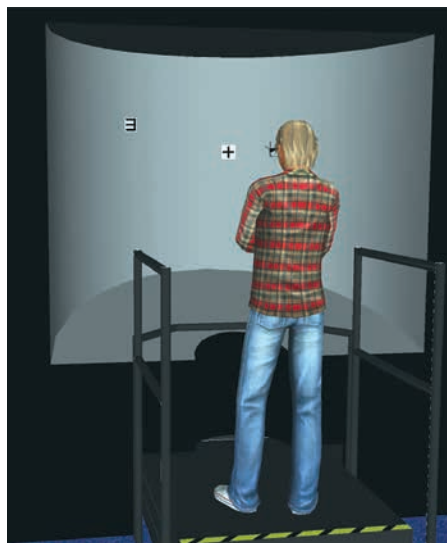


FIGURE 6 Virtual lens simulator. Note fixation cross and "E" target to left of subject. In testing, the target moves and the subject must find it and indicate its orientation.

ing dominant eye™.^{8,9} Studies have also shown that the leading dominant eye™ is the directional guide for the other eye: It is involved in the perception of direction, and it preferentially affects our estimation of an object's location in space.¹⁰

The Leading Dominant Eye™ in Vision

A virtual reality experiment performed by Essilor vision scientists has shown that when blur is present in a lens in front of the leading dominant eye™, the wearer's reaction time is impacted.¹¹ Subjects were selected such that in half of them the leading dominant eye™ was the left eye; the other half had leading dominant right eyes. Subjects first fixated on a central cross and were then shown an off-center target: the capital E from the eye chart. Each time a target was shown, subjects had to perform a saccade to the

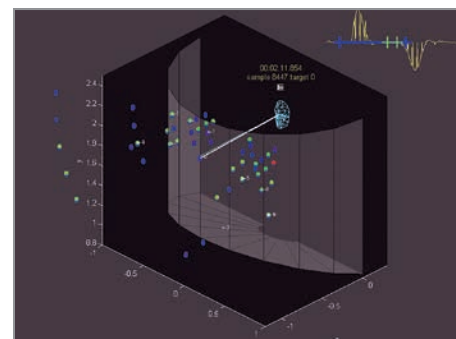


FIGURE 7 Virtual lens simulator with repeated saccades shown.

off-center target and use a joystick to indicate the direction of the "E" (Figure 6).

This was performed in four series of 50 tests per series. During this process, researchers applied both control and test conditions: in control conditions, symmetrical blur was applied to both eyes; in test conditions, an additional 0.75 D of monocular blur was applied randomly to the leading dominant or nondominant eye (Figure 7).

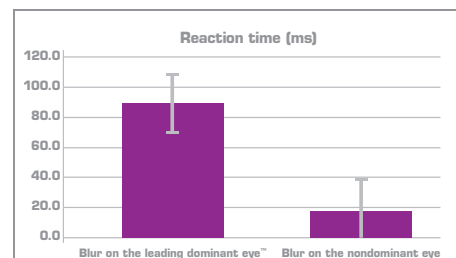


FIGURE 8 Blur on the leading dominant eye™ significantly increases time to acquire and record the target.

The subjects' reaction time was significantly longer when the additional blur was placed on the leading dominant eye™ ($p < 0.05$) (Figure 8). Moreover, the response-time variation compared to control conditions was significant for the leading dominant eye™ but not for the



FIGURE 9 Identification of the leading dominant eye™ with Visioffice® System and the HHMD™.

other eye. That is, blurring the leading dominant eye™ slowed target acquisition time, but blur in the other eye did not.

Which Is the Leading Dominant Eye™?

The leading dominant eye™ is readily identified by using the Varilux S 4D Technology™ Hand Held Measuring Device™ (HHMD™) with the Visioffice® System (Figure 9). The patient holds the device and sights the target through the aperture. Visioffice® System software

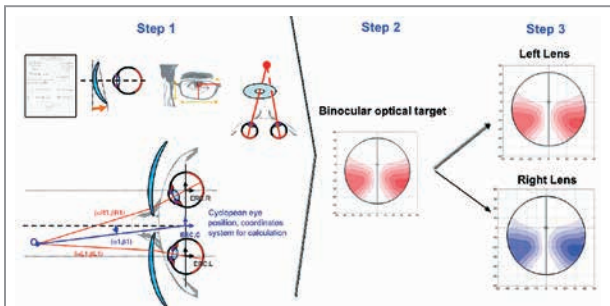


FIGURE 10 To calculate lenses, 4D Technology™ uses SynchronEyes Technology™ to create the widest possible binocular visual fields—and then optimizes the design to ensure the clearest possible vision in the leading dominant eye™.

then automatically determines the dominant eye. Neither the patient nor the examiner has anything else to do.

Once the leading dominant eye™ is known, the rest is automatic. Varilux S 4D Technology™ optimizes the lens to

ensure the sharpest possible vision in the leading dominant eye™ while maintaining stable, expansive binocular vision through the use of SynchronEyes™ and Nanoptix™ technologies. This is accomplished automatically in three steps (Figure 10).

- **Step 1:** SynchronEyes Technology™ builds a personalized binocular system using cyclopean eye coordinates. The design incorporates Nanoptix Technology™ to virtually eliminate “swim.”
- **Step 2:** The targeted binocular design is applied to both eyes, optimizing the right and left lenses for the best possible binocular vision.
- **Step 3:** A binocular optical design is created that simultaneously supports the leading dominant eye™ to optimize reaction time.

CONCLUSION: LIMITLESS VISION™

Three breakthrough technologies are combined in Varilux S 4D Technology™ to give wearers virtually unlimited vision. Two of these technologies, SynchronEyes™ and Nanoptix™, form the foundation for all Varilux S Series™ lenses. 4D Technology™, which requires the Visioffice® System, takes Varilux S 4D™ lenses to the next level of personalization by enhancing vision in the leading dominant eye™.

Nanoptix Technology™ is a revolutionary design that virtually eliminates the “swim effect.” Progressive lens wearers experience “swim” because the surface of a standard progressive lens induces prismatic effects that distort images. These become most noticeable during dynamic vision, when objects appear to move unnaturally, creating a feeling of instability. Nanoptix Technology™ reduces “swim” to a level that cannot be perceived by dividing the lens into optical elements. Then each element is individually determined and corrected to reduce the distur-

tions that produce “swim.” Breakthrough Nanoptix Technology™ changes the fundamental structure of the lens surface to give wearers stability in motion.

Binocular vision enables us to see better with both eyes than with either eye alone. To provide edge-to-edge clear vision—SynchronEyes Technology™ coordinates the design of the left and right lenses to ensure that wherever the viewer looks the left and right lenses will have similar optical profiles. The result is optimized binocularity, providing expansive vision by allowing the eyes to work as one visual system.

Finally, the Varilux S 4D Technology™ not only incorporates the revolutionary SynchronEyes™ and Nanoptix™ technologies, it optimizes vision in the leading dominant eye™. It has been shown that clarity of vision in this eye enables faster visual reaction time™. With the 4D Technology™, wearers experience stability in motion, expansive vision, and faster visual reaction time™.

For wearers of the Varilux S 4D™ lenses, these three technologies—SynchronEyes™, Nanoptix™, and 4D Technology™—work in concert to provide virtually limitless vision™.

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