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VARILUX S SERIES COMPENDIUM

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VARILUX S SERIES™ COMPENDIUM
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This paper will introduce the contribution of Nanoptix Technology™ to the elimination of the "swim effect."

Defining "Swim"

The "swim effect" some progressive lens wearers experience during dynamic visual tasks has long challenged lens designers. Despite decades of work, every progressive lens design to date has induced some degree of "swim." Lens designers' attempts to reduce "swim" have all been hampered by the fact that, up to now, the strategies employed to limit "swim" have had the unwanted side effect of reducing fields of clear vision.

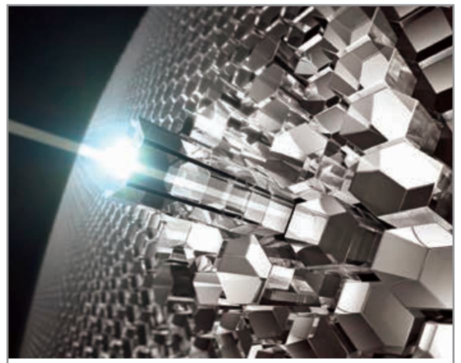

FIGURE 1 Varilux S Series™ lenses are calculated from many tiny optical elements.

Nanoptix Technology™ completely rethinks the lens design process—with the result that Varilux S Series™ lenses virtually eliminate "swim" compared to all other progressive lens designs and still provide expansive vision.

The Origin of "Swim"

By definition, progressive lens power increases continuously from the distance to the near portions of the lens. But this variation of power at the surface of the lens induces image distortion, which is most pronounced in the lower part of the lens where power is greatest.

In static conditions the wearer will experience image deformation: straight lines viewed through the bottom of the lens may appear curved due to prismatic deviation. In dynamic binocular vision—ie, when either the wearer or objects in the visual field are moving—this effect is amplified, and the wearer may experience "swim," as objects appear to move unnaturally in the visual environment.

The "swim effect" is roughly proportional to the increase in prismatic deviation between upper and lower parts of the lens. This can be measured by looking at the difference in horizontal displacement of the image of a vertical line as seen through these two parts of the lens. The displacement, Δx, is a function of the shape of the lens and the power difference from top to bottom. Dividing Δx by the maximum power variation, ΔP, gives us a value, Δd, called the "end-to-end normalized deformation."

Δd is an objective measure of the lens' tendency to distort and can be used as an indicator of the lens' tendency to produce "swim." To minimize "swim," the Δd value of a progressive lens should be close to 0, as it would be in a single-vision lens.

Breaking the Paradigm

Instead of considering the lens as a single, continuous curve, Nanoptix Technology™ reengineers the lens, conceptualizing it as composed of many optical elements (Figure 1). By controlling the length and the position of each element, Nanoptix Technology™ calculates the power and design needed *at each point* to correct the given prescription. Once each element is determined, Varilux S Series™ lenses are built, element by element (Figure 2). The result is a fundamental restructuring of progressive lens geometry that enables the control of prismatic deviation at the element level, virtually eliminating "swim" compared to other progressive lenses.

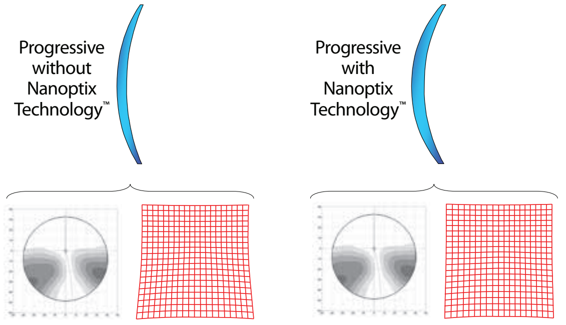

FIGURE 2 Using dynamic vision in a virtual reality environment, subjects compared their perception of a grid as it would appear through a progressive lens either with or without optimization aimed at elimination of "swim." Among subjects with a preference, 73% preferred the optimized design.

Nanoptix Technology™ provides stable, virtually "swim"-free vision. Combining this with SynchronEyes Technology™, which creates lenses optimized for binocular vision, enables Varilux S Series™ lenses to give wearers virtually unlimited vision in progressive lenses. ■

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The Varilux S Series™: Nanoptix Technology™ — A Revolutionary Approach to Fundamental Progressive Addition Lens Structure

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This paper will introduce the contribution of Nanoptix Technology™ to the elimination of the "swim effect."

Introduction

All prior progressive lens designs have been limited by the need for trade-offs and compromise. Before Nanoptix Technology™, for example, all design strategies that aimed to reduce "swim" had the unwanted side effect of narrowing the fields of clear vision. Progressive lenses could have either wide fields or reduced "swim"—but never both at the same time. This white paper will examine what causes "swim," how it has been traditionally managed, and how the breakthrough Nanoptix Technology™ enables "swim" to be dramatically reduced without affecting other lens parameters.

"Swim" Defined

By design, progressive lens curvature changes continuously from the distance to the near portion of the lens. This change in curvature provides a continuous increase in power to give presbyopic wearers clear vision at all distances. But this change in power at the lens surface also induces distortion that the wearer perceives as image deformation, making straight lines appear to be curved in the lower portion of the lens.[1,2]

In static vision—ie, when neither the wearer nor objects in the wearer's environment are moving—the apparent curvature of a straight vertical line will be more pronounced when viewed through the lower than through the upper part of the progressive lens. This is the result of increasing prismatic deviation generated by the lens' power gradient.

In dynamic vision, when the wearer and/or objects in the wearer's visual field are in motion, the distortion effect is amplified, and the wearer may experience "swim," as objects appear to move unnaturally in the visual environment.

Measuring "Swim"

Up to now, some degree of the distortion that causes "swim" has been inherent in all standard progressive lenses due to the continuous power increase—and the resultant increase in prismatic deviation—from top to bottom of the lens. One can calculate the difference in horizontal displacement of a vertical line viewed through the top versus the bottom of a progressive lens. The value of this displacement, Δx, is a function of the difference in power between the two points on the lens and the lens' shape.

Dividing Δx by the maximum power variation, ΔP, yields a value, Δd, which is called the "end-to-end normalized deformation." We can use this value as an objective predictor of "swim": when Δd approaches zero in a progressive lens, as it does in a single vision lens, the "swim effect" is minimized.

The Effects of "Swim"

As noted, the progressive power variation induces image distortion in the lower part of the lens. This impacts peripheral vision, and when the observer is in motion, the effect is amplified. This is "swim": the perception of unnatural movement of objects or the environment. At its worst, "swim" can produce symptoms of motion sickness.

The effect of visual distortion on postural stability has been demonstrated in an experiment conducted by Faubert and Allard.[3] Using a virtual reality chamber to simulate a three-dimensional environment, they were able to create varying levels of dynamic distortion. While exposed to this environment, subjects' posture was monitored by means of sensors on their heads and backs. Faubert and Allard found that postural instability increased with the amplitude of visual distortion.

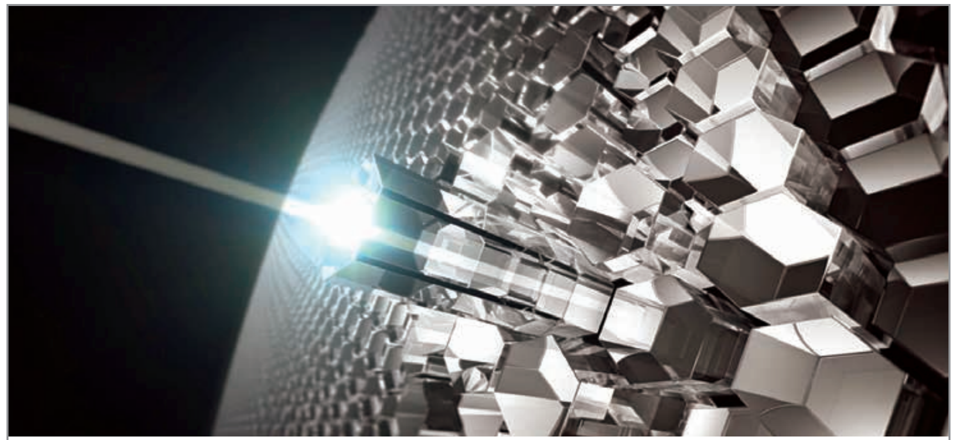

FIGURE 1 Artist's vision of a lens surface divided into elements. In reality, these elements are infinitesimally small, and the surface of the lens perfectly smooth.

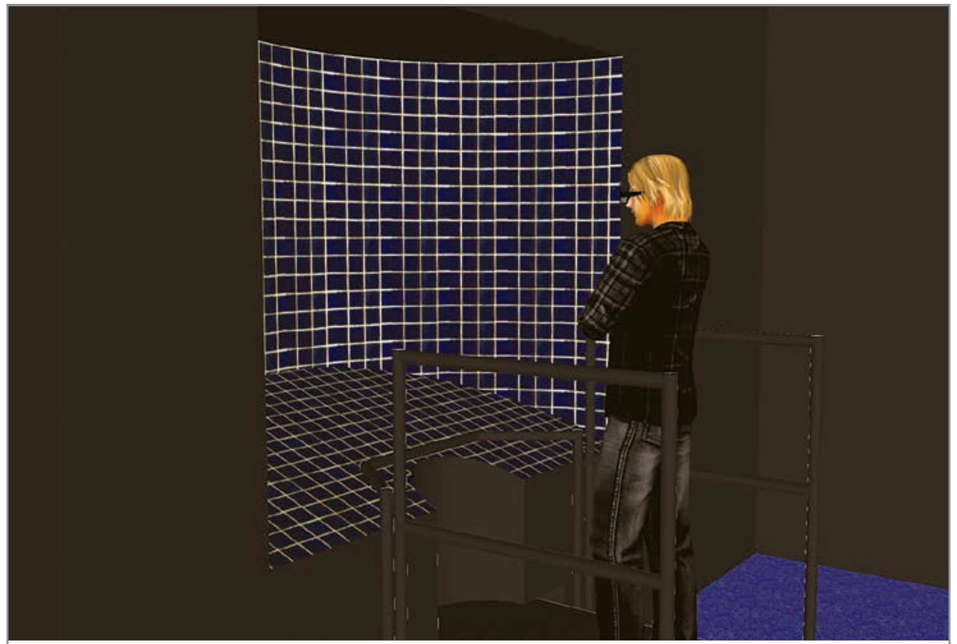

FIGURE 2 The lens simulator creates a controlled, dynamic binocular environment in which space deformation can be observed through virtual lenses, in real time, when moving the head.

Managing "Swim": Past Efforts

As noted, "swim" has been an issue from the very first progressive lenses. To put Nanoptix Technology™ into perspective, it will help to see how greatly it differs from the way "swim" has traditionally been managed in progressive lenses.

Prentice's Rule states that ray deviation increases with distance from the visual axis and with increasing lens power. Since lower power means less ray deviation, designers worked to reduce ray deviation by reducing power variation across the entire lens surface. This can be done by softening the lens design. Softening the design, however, also reduces fields of clear vision—an unwanted but unavoidable consequence.

Revolutionary Nanoptix Technology™

Nanoptix Technology™ completely reengineers the lens calculation process. Using digital surfacing, Nanoptix Technology™ enables designers to take an entirely new approach to "swim." In place of considering the entire lens surface as a continuous curve, Nanoptix Technology™ envisions the lens as many optical elements, each of which defines an optical path (Figure 1). The result is a revolutionary semi-finished progressive

SynchronEyes Technology™: A Powerful, Innovative Approach to Binocular Vision in Progressive Addition Lenses

The second critical technology in Varilux S Series™ lenses is SynchronEyes™, the first technology ever to enhance binocular vision. The human visual system is binocular—in most people, vision is based on the simultaneous perception of images from two eyes. Until now, however, progressive lenses have had to be designed monocularly—the lens design in one eye could not take into account vision in the other eye. The revolutionary SynchronEyes Technology™ breaks this paradigm, and for the first time lens design supports and optimizes binocular vision, allowing both eyes to work together as one visual system. The result is the widest, most expansive field of clear vision.

Binocular vision has three components. The most basic is simultaneous foveal perception, in which light is turned into neural signals sent from each retina to the visual cortex. Fusion within the cortex merges the two images into a single clear image that enables binocular summation. With binocular summation, the brain can process more information from the fused image than from either monocular image alone. Finally, in stereopsis, the visual system builds a three-dimensional representation from the pair of two-dimensional images. Binocular summation is a key element in this process, and better binocular summation means better acuity, contrast sensitivity, color and shape perception, and greater ability to detect and discriminate between objects.

Binocular summation is optimized when the optical quality of retinal images in the two eyes is as similar as possible—the ideal situation being identical (and low) aberration in each eye *for each point of gaze.* SynchronEyes Technology™ makes this possible by using a mathematical construct—the cyclopean eye—to compare and balance aberrations at homologous points in the left and right lenses. (Homologous points are the two points—one on each lens—through which gaze is directed when both eyes are looking at the same point in space.) With SynchronEyes Technology™, the homologous retinal images are balanced with respect to optical quality, and binocular summation is optimized. This is true no matter the direction of gaze.

SynchronEyes Technology™ treats lenses as a pair, with each lens corrected to account for aberrations in the other. The result is balanced images, giving wearers the best possible binocular vision. By treating both eyes as one visual system, SynchronEyes Technology™ provides improved acuity and contrast sensitivity with edge-to-edge expansive vision.

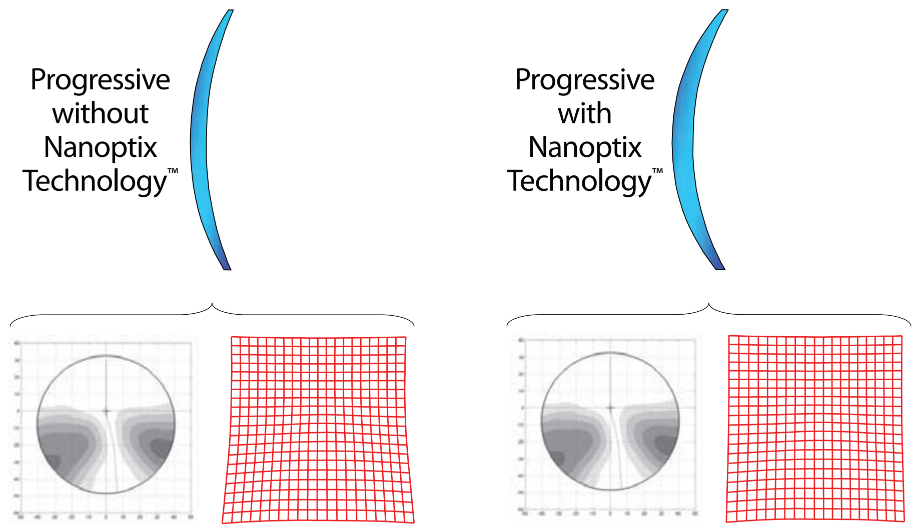

FIGURE 3 Using dynamic vision in a virtual reality environment, subjects compared their perception of a grid as it would appear through a progressive lens either with or without optimization aimed at elimination of "swim." Among subjects with a preference, 73% preferred the optimized design (right).

lens geometry that has never been seen before.

When a Varilux S Series™ lens is calculated, the length and position of each optical element is optimized:

- Each element is first calculated to provide the required local optical design and power suitable for the given wearer and object distance.
- Each element is then individually modified to reduce the prismatic deviation that produces "swim."
- The lens is then assembled element by element.

With Varilux S Series™ lenses, lens shape and power are managed at the individual element level, so that the degree of prismatic deviation can be controlled. Since it is *differences* in prismatic deviation that produce "swim," stabilizing this deviation can greatly reduce "swim;" and this remains true even as add power increases.

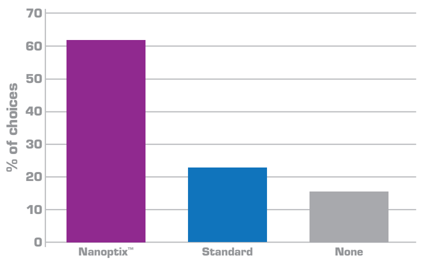

FIGURE 4 Lens geometry created with Nanoptix Technology™ was preferred to standard geometry in tests using virtual reality simulation.

A Perceptible Difference

The Varilux® LiveOptics™ process allows optical designers to model and test concepts early on in the development process (Figure 2). In a virtual reality setting, the vision obtainable with a new lens concept can be accurately simulated, and patient acceptance of the optical effects can be determined immediately (Figure 3).

Using this technology, a randomized, single-blind trial compared the appearance of a grid in dynamic vision as it would look through traditional progressive lenses vs how it would appear with the same lens design but with Nanoptix Technology™ optimization. The difference with Nanoptix Technology™ was readily noticeable: By a margin of almost 3:1 (62% to 23%) subjects selected the dynamic vision with Nanoptix Technology™ optimization over standard progressive lens vision (Figure 4). (In 15% of the choices, subjects had no preference.)

This preliminary study demonstrated that by creating an innovative progressive lens geometry, Nanoptix Technology™ was able to reduce "swim" without disturbing the progressive power gradient.

Clinically Proven

Although well-suited to proof-of-concept testing, virtual reality cannot be a substitute for clinical trials with real lenses worn by typical patients in normal situations. Varilux® is committed to testing and retesting every new design through the LiveOptics™ process. To prove its value, a new lens design must be tested against a well-known standard, typically a best-in-class alternative. Thus, a clinical trial was performed to compare the Varilux S Series™ lens to the highly regarded Varilux Physio Enhanced™ lens.

In the study reported here, 97 experienced progressive lens wearers were tested in a double-masked, randomized, controlled, crossover clinical trial. The distribution of refractive errors and reading adds in the study group closely approximated that of the general population of progressive lens wearers. The study group also paralleled the progressive lens-wearing population at large, with roughly equal numbers of hyperopes, myopes, and emmetropes, and 57% of the subjects having high adds vs 43% with low adds.

The test protocol called for a 1-week washout period, after which patients wore their first set of test lenses (either Varilux S Series™ or Varilux Physio Enhanced™) for 2 weeks, and then evaluated the lenses on a standardized questionnaire. The subjects then switched to the other lenses and wore them for 2 weeks. At the end of the second 2-week study period, subjects performed the same evaluation and stated whether they had a preference between the two lens types.

S Digital Surfacing Technology for Varilux S Series™ Lenses

Achieving the level of accuracy required to create the complex surface geometry of a lens designed with Nanoptix Technology™ demands precision in the digital surfacing process—especially in aligning the front surface with the back surface. With current digital surfacing, positioning errors can occur in lens blocking. While these are within acceptable tolerances for current-generation digitally surfaced lenses, Nanoptix Technology™ demands a higher level of manufacturing precision.

To create lenses calculated with Nanoptix Technology™, the front and back surfaces of each element must be precisely positioned. Achieving this high level of precision surfacing requires a special process called S Digital Surfacing, which uses continuous closed-loop monitoring to ensure error-free alignment of lens surfaces. This makes it possible to cut the front and back surfaces of the lens precisely in relation to each other, so the front surface of each element is precisely aligned with its back surface.

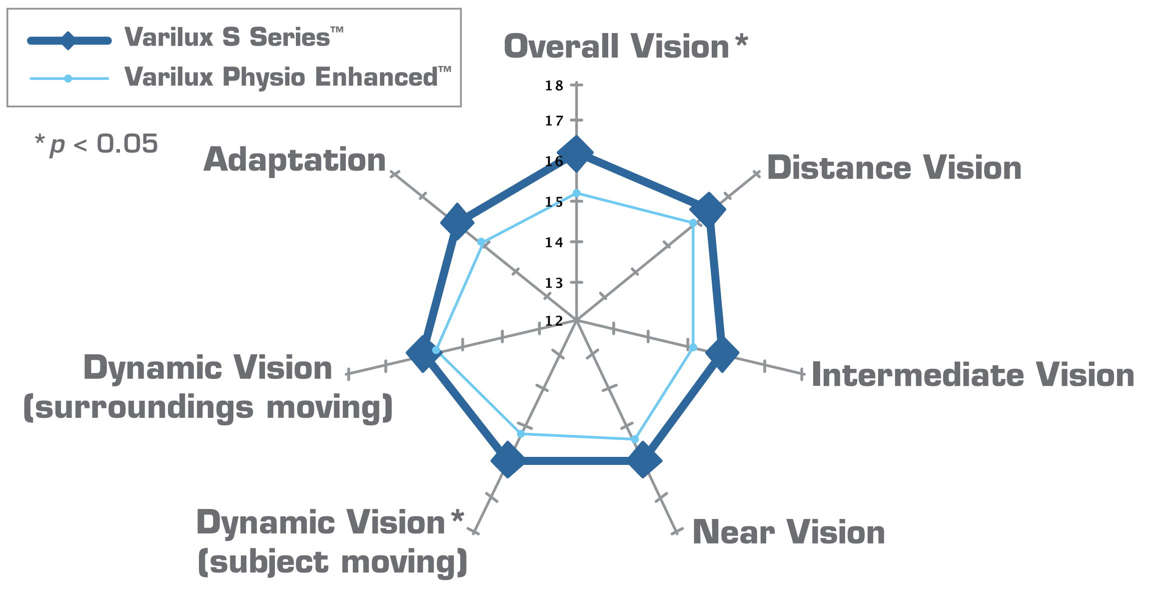

FIGURE 5 Varilux S Series™ lenses were preferred to Varilux Physio Enhanced™ lenses on every parameter tested.

Strong Preference for Varilux S Series™

Despite the lens used for comparison being the gold-standard Varilux Physio Enhanced™, patients showed a strong preference for the Varilux S Series™ lens with Nanoptix™ and SynchronEyes™ technologies. These wearers rated the Varilux S Series™ lenses higher on *every* parameter, including distance, near, and intermediate vision, dynamic vision, adaptation, and overall vision (Figure 5).

Not surprisingly, wearers adapted readily to the lenses—61% adapted either "immediately" or "in a few minutes." And the ratings for quality of dynamic vision—both with the wearer in motion and with the object in motion—were higher with Varilux S Series™ lenses.

This clinical trial proved that, with Nanoptix™ and SynchronEyes™ design technologies, the old limitations no longer hold, and, for the first time, patients can enjoy progressive lenses with wider fields *and* reduced "swim." The concept proved in virtual reality testing was confirmed in a real-world clinical trial.

Conclusion: Limitless Vision™

Nanoptix Technology™ is a revolutionary design technology that provides stable progressive lens vision by dramatically reducing the "swim effect." A result of increasing prismatic distortion induced by the progressive lens' power gradient, "swim" affects dynamic vision, causing objects to appear to move unnaturally and creating a feeling of instability for the wearer.

Nanoptix Technology™ entirely re-engineers the lens calculation process by envisioning the lens as many tiny optical elements. This enables the creation of a new and unprecedented lens geometry that allows lens designers to manage prismatic deviation at the element level. The result is lenses with minimal difference in ray deviation across the progressive gradient. This reduces the level of distortion and virtually eliminates the "swim effect" compared to other premium progressive lenses.

Working with Nanoptix Technology™, SynchronEyes Technology™ coordinates and balances optical quality in both lenses so the eyes work together as one visual system. This breakthrough technology ensures expansive fields of clear vision. For wearers of the Varilux S Series™ lenses, the SynchronEyes™ and Nanoptix™ technologies work in concert to assure limitless vision™.

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The Varilux S Series™: SynchronEyes Technology™— A Powerful, Innovative Approach to Binocular Vision in Progressive Addition Lenses

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

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

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This paper will introduce SynchronEyes Technology™ and describe how it calculates lenses as a pair for expansive binocular vision.

Binocular Vision

The human visual system is inherently binocular. In the absence of any ocular or neurological pathology, humans can see significantly better with both eyes than with either eye alone. Up to now, technological limitations have made it impossible for progressive lenses to work with the eyes' natural binocularity. Instead, it has been necessary to design and calculate lenses as if each eye were a monocular system to be optimized without reference to the fellow eye.

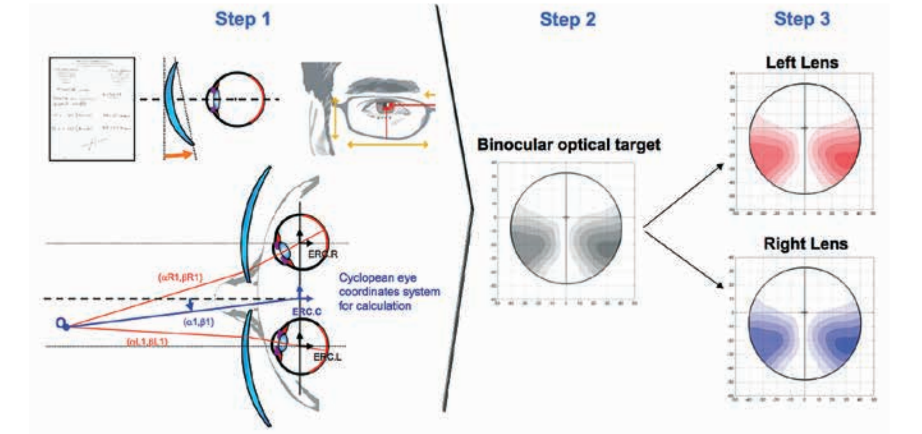

FIGURE 1 Beginning with individual eye parameters, SynchronEyes Technology™ creates a binocular optical system in which optical quality is balanced at homologous points on each lens.

Binocular vision takes place when the brain is able to integrate the slightly different images from each retina to create a single three-dimensional representation. For the brain to fuse the images from the two eyes, the retinal images have to be similar with respect to size, shape, color, brightness, and focus. Research has also shown that image fusion—and hence the quality of binocular vision—is best when the optical quality of the two retinal images is similar.

Enabling Binocularity

The ideal situation for binocular vision, then, is low aberrations in each eye *at each point of gaze*; the challenge for lens designers is to create this condition for every point of gaze.

When optical design is determined separately for each eye, it is virtually impossible to balance optical quality at each point of gaze because of each lens' distinct sphere, cylinder, and axis characteristics. Without a way to create equivalent levels of optical quality in *both* eyes at every direction of gaze, the primary requirement for optimal binocular vision cannot be met.

SynchronEyes Technology™ is a revolutionary technology that uses a mathematical model—the cyclopean eye—to balance aberrations at homologous points in the left and right lenses. (Homologous points are the two points—one on each lens—through which gaze is directed when both eyes are looking at the same point in space). With SynchronEyes Technology™, the homologous retinal images are balanced with respect to optical quality, and binocular vision is optimized.

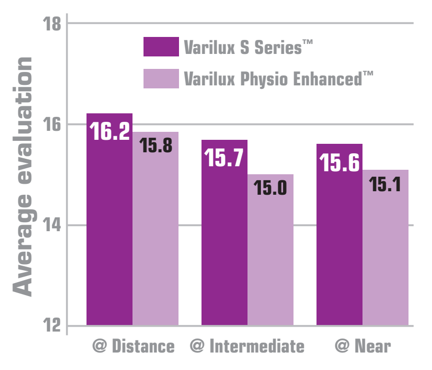

FIGURE 2 In wearer tests, subjects found wider fields of vision at all distances in Varilux S Series™ lenses than in industry-leading Varilux Physio Enhanced™ lenses. (Evaluations based on a 20-point scale.)

SynchronEyes Technology™ creates lenses in a three-step process (Figure 1). First, the parameters of each eye are measured and recorded; then, a binocular optical system is designed based on wearer parameters; and finally, the binocular optical design is applied, with the right and left lenses optimized to work together. As this takes place, Nanoptix Technology™ ensures that the lenses are virtually "swim"-free. The resulting lenses provide balanced retinal images with low aberration levels, giving wearers stable and expansive *binocular* vision—made possible by allowing the eyes to work together as one visual system (Figure 2). ■

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This paper will focus on SynchronEyes Technology™ and how, for the first time ever, a lens design technology is able to calculate left and right lenses simultaneously to achieve exceptional *binocular* vision.

Introduction

The human visual system is inherently binocular. Separated by an average of 63 mm, the eyes register slightly different images, but the brain is structured to fuse the two images to form a single, unified picture of the world. In the absence of ocular or neurological pathology, humans can see significantly better with both eyes than with their best eye alone.

Up to now, technological limitations have made it impossible for progressive lenses to work with the eyes' natural binocularity. Instead, it has been necessary to design and calculate progressive lenses as if each eye were a monocular system, to be optimized without reference to the fellow eye. That changed with the advent of the revolutionary Varilux S Series™ lenses. With two groundbreaking new technologies—SynchronEyes™ and Nanoptix™—Varilux S Series™ lenses for the first time take advantage of our natural binocularity to create virtually unlimited fields of clear vision. Working together, SynchronEyes™ and Nanoptix™ technologies ensure that all Varilux S Series™ lenses offer clear binocular vision that virtually eliminates "swim" compared to other premium progressive lenses.

Binocular Vision

The neural processes that enable binocular vision take place in three stages. In the first stage, *simultaneous foveal perception*, light is turned into neural signals that are sent simultaneously from each retina to the brain's visual cortex. Although the images are slightly different, the brain accepts both.

In the next stage, *fusion*, the visual cortex creates a single clear image from the two retinal images. For fusion to take place, the two images must be similar in size, shape, sharpness, brightness, and color. In the third step of binocular vision, *stereopsis*, the visual system builds a three-dimensional representation from the pair of two-dimensional retinal images.

Benefits of Binocularity

Binocular vision has three primary benefits: 1) stereopsis, 2) accurate perception of one's position in space, and 3) binocular summation. *Binocular summation* requires good fusion and occurs when visual performance with both eyes is superior to visual performance with the best eye alone. This integration of information from each eye improves visual acuity, contrast sensitivity, and depth perception.

But what can enhance binocular summation? Jimenez and coworkers showed that binocular summation is best when the level of higher order aberration (HOA) is similar in both eyes.[1]

This was reinforced by Castro and coworkers, who demonstrated that binocular summation was greatest when the images in each eye were equal in terms of optical quality, as measured by the Strehl ratio of each eye.[2] (The Strehl ratio, a widely recognized indicator of optical quality, is the ratio of a theoretical optimum point spread function to the measured point spread function.) 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 1).

There are proven benefits to binocular summation. Jones and Lee showed that binocularly concordant information (which enables binocular summation) significantly enhances color and shape perception.[3] Others have shown that binocular summation can significantly improve object detection and discrimination.[4-6]

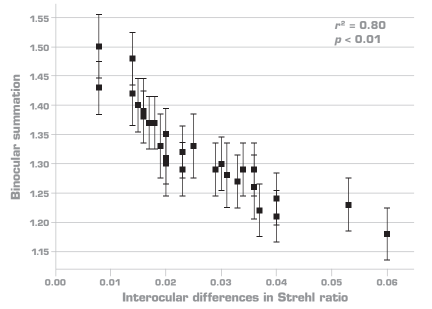

FIGURE 1 The quality of binocular summation declines as the between-eye Strehl ratio increases. (The Strehl ratio is a measure of image quality; and the graph shows that as the disparity in image quality grows, the level of binocular summation declines.) *Image adapted from reference 2.*

Taken together, these studies demonstrate that the greater the similarity between the two monocular images delivered to the brain, the better the quality of binocular summation. And the better the binocular summation, the better the acuity, contrast sensitivity, color and shape perception, and the ability to detect and discriminate between objects.

Managing Binocularity: Before SynchronEyes Technology™

In theory, then, optimizing binocular summation by delivering two images with equivalent levels of aberration to the brain ought to be a strategy for improving vision. Indeed, there have long been claims that various lenses supported binocular vision by managing left/right image imbalance in either of two ways.

The first of these is the location of vision zones to facilitate convergence. Distance, intermediate, and near zones have to be centered along the line on which the visual axis intersects the lens as the eye transitions from distance through intermediate to near vision. In particular, the center of the near vision zone has to be inset (shifted nasally) with respect to the center of the distance zone. Positioning of the zones must take into account both the eye's natural convergence and the lens' prismatic effects, and the required inset is a function of monocular pupillary distance, vertex distance, reading distance, and prescription (distance power and add power).

A second, and now somewhat dated, strategy for supporting binocularity is the distribution of powers and aberrations across the lens, so that when gaze shifts off-axis the images in each eye are balanced with respect to optical quality. A number of lenses have claimed to offer this "nasal/temporal balance." Despite such claims, up to now all lens calculations have been based on monocular models that take into account, for a given eye, the rotational center, prescription, and perhaps some other parameters (eg, position of wear)—but for *that eye only.* The specifics of the other eye are never factored in. Monocular optimization can ensure good performance for each eye, but it cannot guarantee the balance between right and left retinal images.

Designing a progressive lens that optimizes binocular vision requires that the lenses enhance binocular summation; and this, in turn, requires the ability to ensure images of equivalent optical quality in each eye for each point of gaze.

Aberration Distribution

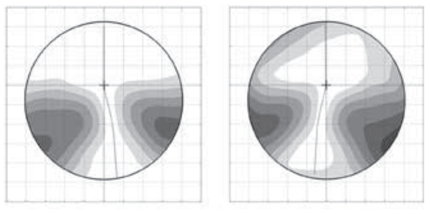

FIGURE 2 Small differences in prescription between the left and right eyes can have a major impact on the distribution of aberrations in each lens.

While it is easy to state, achieving equal levels of optical quality in each eye at each point of gaze is extremely difficult. First, matching optical quality levels between lenses is inherently challenging, because aberrations are affected by lens power, which nearly always differs between a patient's two eyes (Figure 2). Sphere power is important in determining aberrations, but astigmatism correction has an even greater effect on the distribution of aberrations across a lens. Even keeping sphere, cylinder, and add powers constant, just changing the axis of astigmatism produces significant differences in the pattern of aberrations.

When optical design is determined separately for each eye, it is virtually impossible to balance optical quality at each point of gaze because each lens has different power and aberration distributions. With the appropriate software, digital surfacing allows aberrations to be corrected monocularly, but without a way to coordinate the distribution of aberrations between lenses, the key condition for optimal binocular vision—equivalent levels of optical quality in both eyes at every direction of gaze—cannot be met.

Equivalent Image Quality at Each Gaze Point

As we have seen, unless the viewer is looking to "infinity" through the center of each lens, there is no reason to assume that optical quality in the portions of each lens through which gaze is directed will be equivalent or even similar.

In Figure 3, for example, the two eyes are looking at a point in space "O," and it is clear that the left and right eyes look through different points on their respective spectacle lenses. We call these points *homologous* to indicate their relationship as the points on each lens through which gaze passes when both eyes are fixed on the same point in space.

For binocular optimization, we need the ability to produce an image of equivalent optical quality at all homologous points on both lenses. And this is exactly what the SynchronEyes Technology™ does: it enhances binocularity by ensuring equivalent optical quality at all homologous points on both lenses. This can only be achieved with a means for mapping and comparing aberrations at homologous points, allowing both eyes to work together as one visual system.

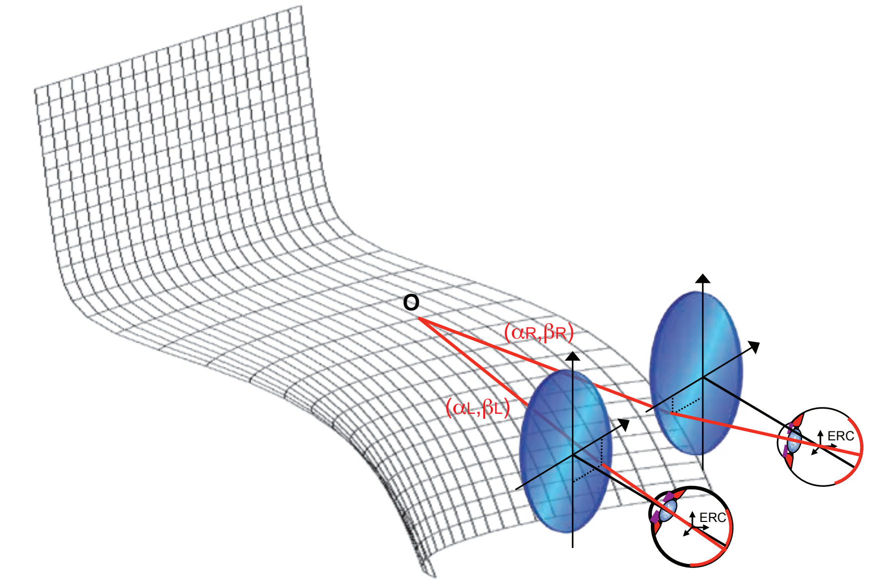

FIGURE 3 Point O, a point in three-dimensional space, as seen by the left and right eyes. Note that in order to see the point, the two eyes' gaze is directed at different angles and through different portions of the lens. (ERC = eye rotation center.)

The Cyclopean Eye

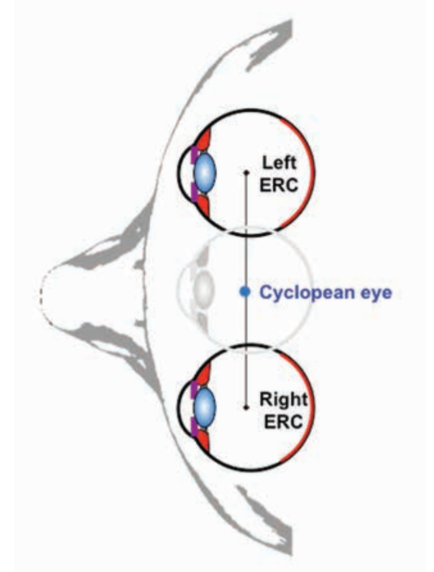

FIGURE 4 The cyclopean eye is a theoretical eye whose center is midway between the eye rotation centers (ERCs) of the left and right eyes.

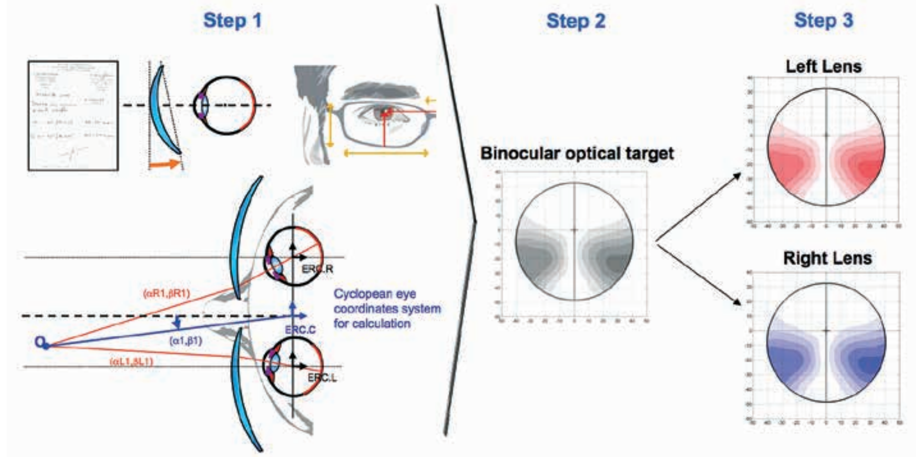

FIGURE 5 Beginning with individual eye parameters, SynchronEyes Technology™ creates a binocular optical system in which homologous points on each lens are matched with regard to aberration levels.

In SynchronEyes Technology™, the mapping of homologous points is accomplished by means of a theoretical model called the *cyclopean eye*, named for the mythical Greek Cyclops, who had a single eye in the middle of his forehead. In this model, the center of the cyclopean eye is the point midway between the eye rotation centers (ERCs) of the left and right eyes (Figure 4). By using the cyclopean eye, engineers can build a coordinate system in which the lens design for the left eye can be compared to and brought into conformity with that of the right eye. This ability to overlap and compare all homologous points on a pair of lenses is the basis of the revolutionary SynchronEyes™ design technology—technology that, for the first time, allows retinal image quality in one eye to be accurately coordinated with that of the fellow eye.

Using this unique, proprietary framework, Varilux S Series™ lenses are built in three steps (Figure 5):

- **Step 1:** The parameters of each eye are measured and recorded.
- **Step 2:** A binocular optical system is designed based on wearer parameters.
- **Step 3:** The binocular optical design is applied, with the right and left lenses optimized according to the targeted binocular optical design.

Because binocular summation produces clearer vision than either eye could achieve alone, balancing retinal image quality with SynchronEyes Technology™ provides a level of expansive *binocular* vision never before possible in progressive lenses.

Nanoptix Technology™: A Breakthrough Technology Virtually Eliminates "Swim"

By design, the power of a progressive lens increases at a continuous, controlled rate from the distance to the near portion of the lens, to provide the presbyopic wearer with clear vision at all viewing distances. But this continuous change in power induces distortion in the lower part of the lens, which the wearer perceives as image deformation.

In static conditions, when neither the wearer nor the object of regard is moving, straight lines seen through the lower part of the lens will appear slightly curved, with the curvature increasing as lens power increases from the distance to the near portion of the lens. This is due to increasing prismatic deviation generated by the increasing power of the progressive curve.

In dynamic binocular vision, when either the wearer is in motion and/or objects in view are moving, this effect is amplified, and the wearer may experience the "swim effect"—which in extreme cases can induce motion sickness—because the objects are perceived to be moving unnaturally with respect to their environment. In the past, this phenomenon has affected all progressive lenses because, in the standard progressive lens, the base curve and the power increase continuously from the upper to the lower portions of the lens.

The "swim effect" is linked to the *change* in prismatic deviation as power increases from top to bottom of the lens. This can be quantified: The difference in horizontal displacement of a vertical line seen through a point near the top of the lens and the same line seen through a point lower on the lens is a value called Δx. Δx is a function of the difference in power and the shape of the lens. Dividing Δx by the maximum power variation ΔP, gives us a value, Δd, that we can use as an objective measure of "swim." Called the "end-to-end normalized deformation," the closer this value is to zero—as it would be in a single vision lens—the less "swim" a lens will create.

With Nanoptix Technology™, instead of considering the lens as single continuous curve, each lens is calculated as if it was made up of thousands of optical elements. The length and position of each element can be controlled in order to meet the precise requirements of the design and the power, while also reducing the value of Δd, to create a lens with reduced "swim." Thus, with Nanoptix Technology™, the lens is built element by element, completely reengineering the fundamental shape of the lens.

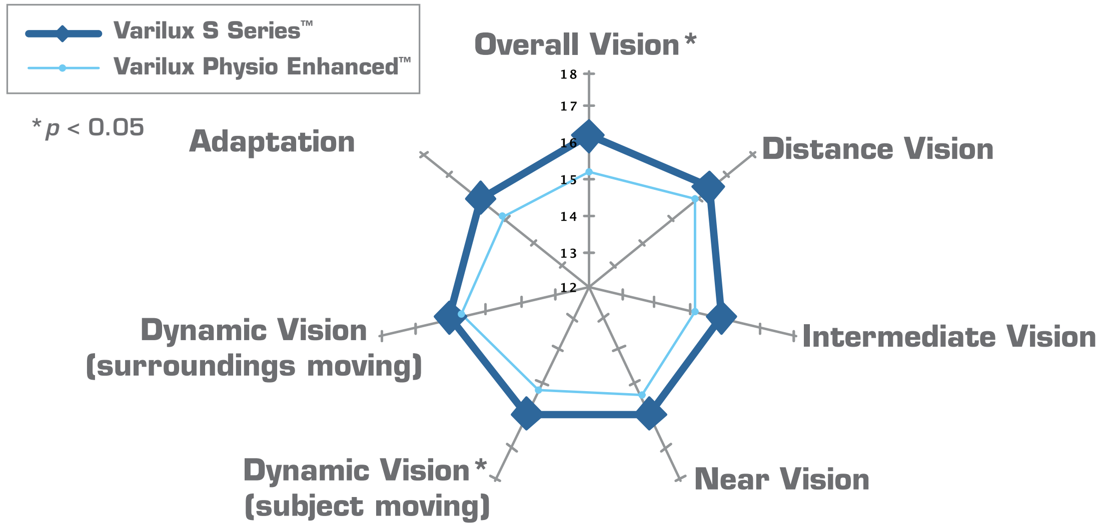

FIGURE 6 In a double-masked crossover study of 97 experienced progressive lens wearers, Varilux S Series™ lenses were preferred over highly regarded Varilux Physio Enhanced™ lenses in every parameter tested.

Clinical Testing Validates Claims

Varilux® is committed to exhaustive testing of every new lens design before it is released. A critical element of this testing involves masked, prospective, randomized clinical trials with real patients. In one such study, a group of 97 experienced progressive lens wearers compared Varilux S Series™ lenses to Varilux Physio Enhanced™ lenses, which are regarded by many as the best progressive lens design currently on the market.

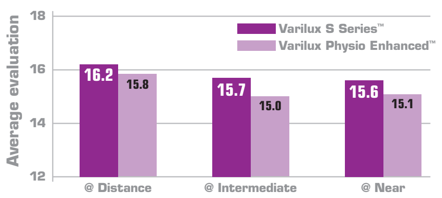

FIGURE 7 In a randomized clinical trial, 97 wearers of Varilux Physio Enhanced™ and Varilux S Series™ lenses rated the lenses for quality of vision and width of visual field (the results of these two questions have been averaged together). Note the clear preference for Varilux S Series™, despite the high ratings that Varilux Physio Enhanced™ has always enjoyed among wearers.

The study protocol called for a 1-week washout period, after which subjects were randomized to wear either Varilux S Series™ or Varilux Physio Enhanced™ lenses. In the first trial period subjects wore their lenses for 2 weeks and then evaluated the lenses on a standardized questionnaire. The subjects then switched to the other lenses and wore them for 2 weeks. At the end of the second 2-week study period, subjects performed the same evaluation and stated whether they had a preference between the two lens designs.

Strong Preference for Varilux S Series™

Subjects rated their lenses on a 20-point scale. A look at the spider graph in Figure 6 shows that these wearers rated the Varilux S Series™ lenses higher on *every* parameter, including distance, near, and intermediate vision, dynamic vision, adaptation, and overall vision.

To judge the effect of SynchronEyes Technology™, a new variable was created: "quality and width of vision." To assess this variable, subjects were asked to separately rate (on the 20-point scale) their distance, intermediate, and near vision. They were also asked to rate for each distance the width of the field of clear vision. Figure 7 shows the results of the two questions (which have been averaged to create the new single variable: quality and width of vision). Varilux S Series™ lenses outperformed Varilux Physio Enhanced™ lenses, demonstrating that with SynchronEyes Technology™, Varilux S Series™ lenses are able to provide wider fields of clear vision at every distance.

Conclusion

Binocular vision enables us to see better with both eyes than with either eye alone, but until the advent of SychronEyes Technology™, progressive lenses could not be designed to optimize binocularity. Because binocular vision is optimized—providing a maximally enlarged area of sharp, clear vision—when the retinal images in each eye are similar, SynchronEyes Technology™ coordinates the design of the left and right lenses to ensure that, wherever the viewer looks, the left and right lenses will provide similar quality images. The result is optimized binocularity, allowing both eyes to function as one visual system.

SynchronEyes™ and Nanoptix™, two breakthrough technologies, are combined in Varilux S Series™ lenses to produce the most stable, expansive vision ever in a progressive lens.

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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.)

This paper will describe how 4D Technology™ can shorten visual reaction time by sharpening vision in the leading dominant eye™.

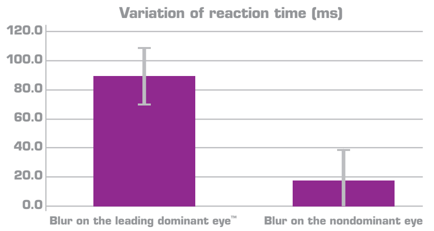

FIGURE 2 In a test system, when blur is placed on the leading dominant eye™, visual response time is significantly greater than when equal blur is placed on the fellow eye.

FIGURE 3 Determination of the leading-dominant eye with the Visioffice® System Hand Held Measuring Device™. The determination is entirely automatic: no action on the part of the eyecare professional is required.

4D Technology™: Faster Visual Reaction Time™

The leading dominant eye™ is the eye that leads the other eye in perceptual and motor tasks. For example, when gaze shifts to a new target, it is the leading dominant eye™ that acquires the target first and leads the fellow eye. Research has demonstrated that the clearer the vision in the leading dominant eye™, the faster a subject is able to shift vision to a new target (Figures 1 and 2). The key to improving visual reaction time, then, is to optimize vision in the leading dominant eye™. This is the goal of the Varilux S 4D Technology™.

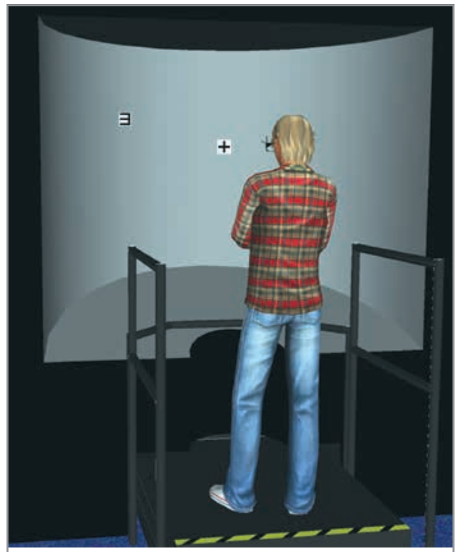

FIGURE 1 Target acquisition test device. Subjects looking straight ahead were shown an off-axis target. Time to start of head movement and target acquisition were measured.

4D Technology™ uses the Essilor Visioffice® System to measure individual personalization parameters and the Visioffice® System Hand Held Measuring Device™ to determine the leading dominant eye™ (Figure 3). The technology then optimizes the lens design to ensure the clearest possible vision in the leading dominant eye™, while maintaining the best possible binocular vision. This is accomplished in three steps.

- **Step 1:** SynchronEyes Technology™ uses wearer data to develop an integrated binocular coordinate system based on the concept of the "cyclopean eye".
- **Step 2:** A targeted binocular design is applied to both lenses, optimizing each for the best possible binocular vision. At the same time, the incorporation of Nanoptix Technology™ ensures stable dynamic vision.
- **Step 3:** 4D Technology™ optimizes vision for the leading dominant eye™, enhancing visual reaction time while maintaining optimal binocular vision.

Conclusion: A Revolution in Lens Personalization

In addition to its revolutionary 4D Technology™, every Varilux S 4D™ lens incorporates Nanoptix Technology™ to provide stability in motion, and SynchronEyes Technology™ to provide expansive vision by allowing the two eyes to work as one visual system.

Using the Essilor Visioffice® System to take complete position-of-wear measurements and to determine the leading dominant eye™ makes possible the next level of personalization in progressive lenses. Optimizing vision in the leading dominant eye™ provides patients with the best vision and the fastest possible visual reaction times for the ultimate in personalization. ■

For additional information:
www.VariluxUSA.com/variluxSSeries
– Technical Information

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:

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- **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.

SYNCHRONEYES 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 1).

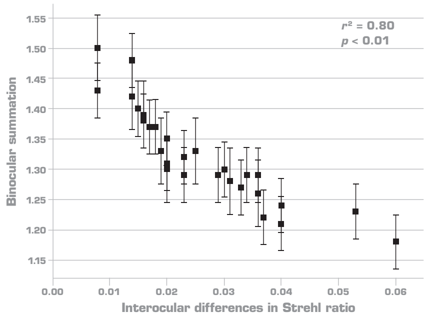

FIGURE 1 Between-eye similarity in Strehl ratio is correlated with binocular summation. *(Image adapted from reference 4.)*

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 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.

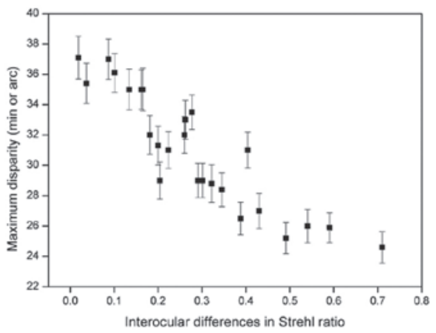

FIGURE 2 Between-eye similarity in Strehl ratio is inversely correlated with binocular disparity (as the two eyes' Strehl ratios approach one another, stereopsis is improved). *(Source: Castro JJ, Jiménez JR, Ortiz C, Alarcon A. Retinal-image quality and maximum disparity.* J Mod Opt. *2010 January;57:103-6.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

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

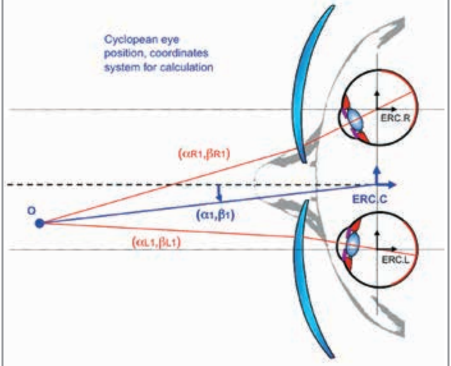

FIGURE 3 The cyclopean coordinate system.

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, manufacturers 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.

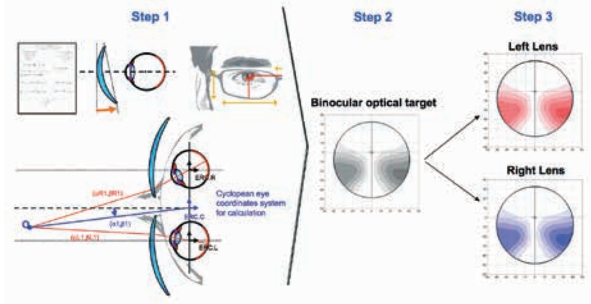

FIGURE 4 Steps by which SynchronEyes Technology™ creates a binocularly optimized lens.

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 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.

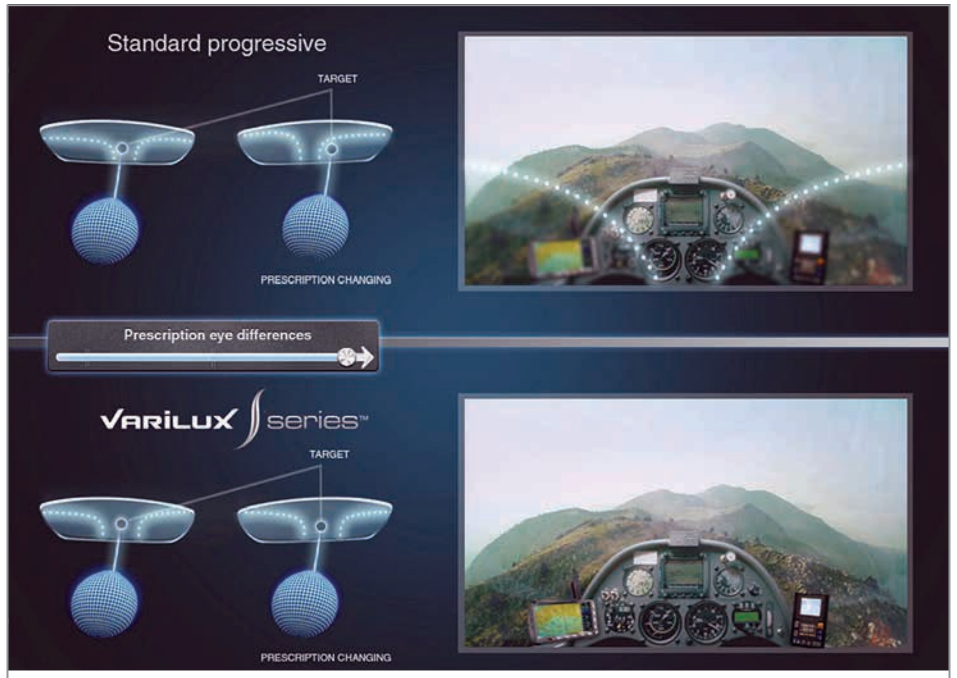

FIGURE 5 Varilux S Series™ vs a standard progressive lens.

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 strongly 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 leading 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]

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.

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

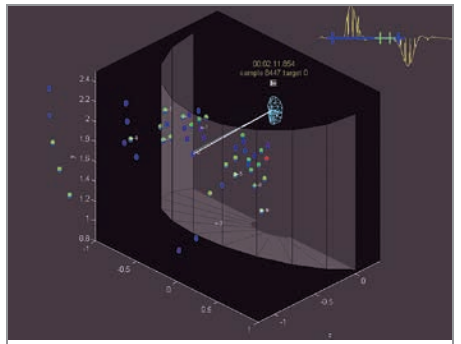

FIGURE 7 Virtual lens simulator with repeated saccades shown.

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).

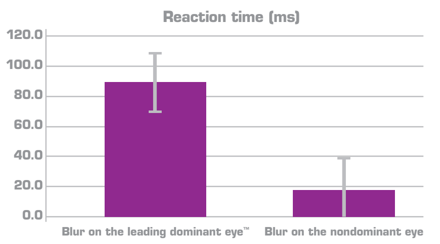

FIGURE 8 Blur on the leading dominant eye™ significantly increases time to acquire and record the target.

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

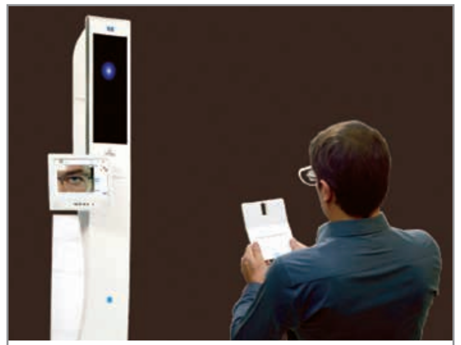

FIGURE 9 Identification of the leading dominant eye™ with Visioffice® System and the HHMD™.

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

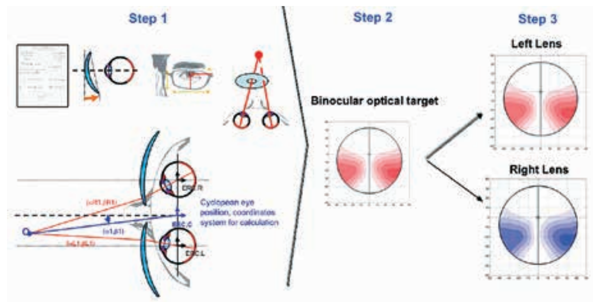

FIGURE 10 To calculate lenses, 4D Technology™ uses SynchronEyes Technology™ to create the widest possible binocular visual fields—and then optimizes the design to ensure the clearest possible vision in the leading dominant eye™.

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 distortions 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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LVAR200970 PDF/ETH 10/12

The Leading Dominant Eye™ During Target Saccades

A study reported at the 2012 ARVO meeting demonstrates that better visual acuity in the leading dominant eye™ can speed visual reaction time.

Introduction

We can define ocular dominance as the tendency of the brain to give priority to input from one eye. When that input involves visual tracking, we refer to the preferred eye as the leading dominant eye™. This eye has been shown to guide the fellow eye when the direction of gaze changes.[1] Multiple studies have shown that the leading dominant eye™ is more sensitive to its environment than the other eye, and the brain processes information from the leading dominant eye™ more rapidly.[2-5]

These prior observations led a group of R&D scientists at Essilor's Paris research center to theorize that optimizing vision in the leading dominant eye™ could potentially speed up visual reaction time. As part of their testing of this concept, they devised an experiment to study whether a clearer image in the leading dominant eye™ affected head movement and visual reaction time.

FIGURE 1 The testing device.

Study Design

Using the testing device pictured in Figure 1, subjects looking at a central fixation cross (in straight-ahead gaze) were presented with a peripheral target in the form of a letter E. Subjects used a joypad to indicate the letter's orientation. This process was repeated with targets shown at different positions to the left and right of, and above and below the center.

Eight subjects were enrolled: four with right-eye dominance and four with left-eye dominance. The control condition was equal blur in both eyes (at least 1 D of blur was used to induce head movement). In the test condition, an additional monocular blur of 0.75 D over the control condition was added on either the leading dominant eye™ or nondominant eye. Targets were displayed randomly. The time to button press was recorded, and subjects' head movements were measured and recorded using an optical tracking device.

FIGURE 2 Mean response times. (Error bars indicate confidence intervals).

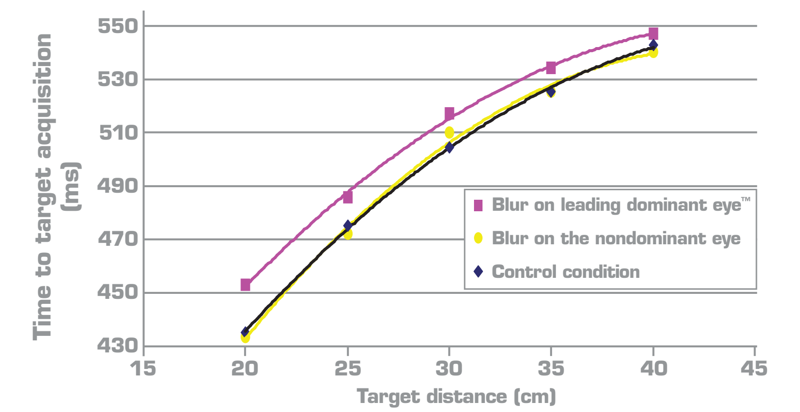

FIGURE 3 Target acquisition was fastest when added blur was placed on the nondominant eye.

Results

The mean response time was significantly greater when the additional blur was placed on the leading dominant eye™ compared to when it was placed on the fellow eye (90 milliseconds vs 20 ms; $p < 0.05$) (Figure 2). Head movement tended to take longer when the additional blur was on the leading dominant eye™ ($p < 0.1$) (Figure 3). No significant differences were found between patients with left-eye dominance and right-eye dominance.

Conclusion

These results demonstrate that the leading dominant eye™ plays a disproportionate role in target acquisition and visual response time, and they suggest that optimizing vision in the leading dominant eye™ may be a strategy for enabling lens wearers to achieve faster visual responses. ■

Based on the poster by I. Poulain, G. Marin, K. Baranton, and D. Paillé: "Role of the Sighting Dominant Eye during Target Saccades," presented at the ARVO Annual Meeting, Ft Lauderdale, FL; May 6-9, 2012.

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Effect of Progressive Lens Shape on Space Perception

Presented at the 2012 meeting of the European Academy of Optometry and Optics, this study used virtual reality simulation to compare the degree of swim perceived in dynamic vision by two lens designs: one a traditional progressive lens, and the other a revolutionary new approach to progressive lens geometry.

Introduction

The increase in power from the top to the bottom of a progressive lens creates increasing amounts of prism which induces increasing degrees of image deviation.[1] This distortion becomes most noticeable and most disturbing during dynamic vision, where it produces the well-known "swim effect."[2-4] While optical designers have long worked to minimize "swim," it has been impossible with prior technology to do so without also reducing visual field size.

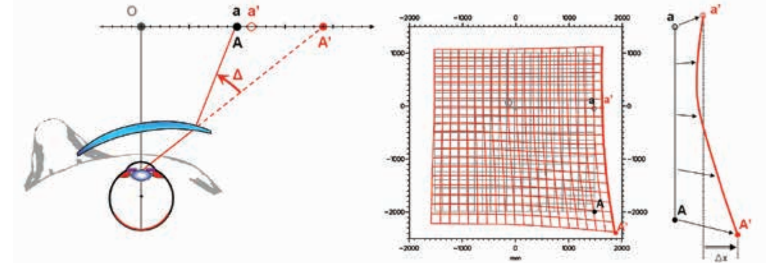

FIGURE 1 Ray tracing enables the image of an object (eg, the gray grid) to be mapped as it would be seen through a progressive lens (the red grid). Note that the lateral displacement from a to a' of an object viewed through the top of the lens is much smaller than the same degree of lateral displacement viewed through the bottom of the lens (A to A').

One can quantify the "swim effect:" The difference in horizontal displacement of a vertical line seen through the upper and the lower portions of the lens is a value we can call Δx. This value is a function of the top-to-bottom change in power and the shape of the lens. By dividing Δx by the maximum power variation ΔP, we can derive an objective criterion of "swim," Δd, which is the *end-to-end normalized deformation*. To minimize "swim," Δd must be close to 0, as it is in a single vision lens.

Challenged to reduce "swim" without decreasing field size, Essilor scientists explored every aspect of the lens design process. The result was a revolutionary new design technology called Nanoptix Technology™, which conceptualizes the lens as composed of tiny optical elements, each of which can be individually corrected to bring Δd close to zero, while respecting the progressive gradient. This study used virtual reality simulation to provide proof-of-concept that this revolutionary lens geometry could produce clinically meaningful results.

Methods

The effects of any given curve on the image of a physical object (eg, a grid) can be mapped (Figure 1) and then modeled in a virtual reality environment (Figure 2).[5] This study used a virtual reality simulator to compare the effects on dynamic vision of two lens designs: a classic progressive lens design and a design with the new geometry designed to reduce "swim."

Using the virtual reality simulator, 10 subjects were shown two images of a grid and asked to compare the images in dynamic vision. Presented in random order, one was a grid as it would be seen through a standard progressive design and the other was a grid as it would appear through the new lens geometry. In each comparison, subjects were asked to state a preference. Each subject made at least four comparisons. Scoring was based on the total number of times each image was chosen as preferred (rather than on individual subject preference).

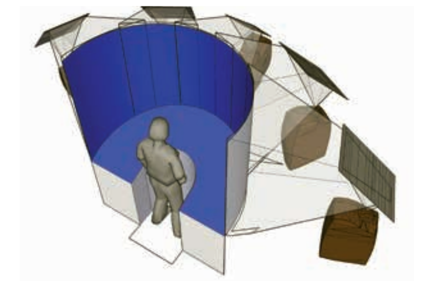

FIGURE 2 The virtual reality testing device's stereoscopic display allows real-time simulation of dynamic binocular space deformation, as seen through virtual lenses when moving the head. *(Courtesy of Barco.)*

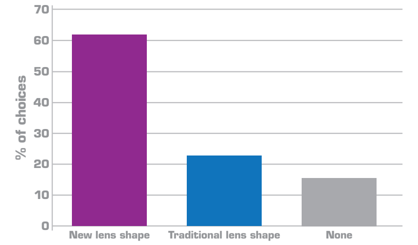

FIGURE 3 In dynamic vision, viewers showed a strong preference for images as they would be seen through the new "swim" geometry compared to traditional progressive lens geometry.

Results

Comparing the grids in dynamic vision, the grid produced by the optimized geometry was preferred in 62% of the comparisons. The grid produced by the standard progressive design was preferred in 23% (Figure 3). There was no preference in 15% of the comparisons.

Conclusion

In this study, Essilor vision scientists demonstrated that "swim" could be quantified, and that an innovative lens geometry could provide a clinically meaningful reduction in "swim." Study subjects clearly preferred the virtual reality image provided by the revolutionary new progressive lens geometry to that provided by ordinary progressive lens optics. ■

Based on the poster by C. Guilloux, H. de Rossi, G. Marin, B. Bourdoncle, M. Hernandez, L. Calixte, F. Karioty: "The importance of the ophthalmic progressive lens shape on the space perception" presented at the European Academy of Optometry and Optics Meeting, Dublin, Ireland; April 20-22, 2012.

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The Role of the Sighting Dominant Eye during Target Saccades

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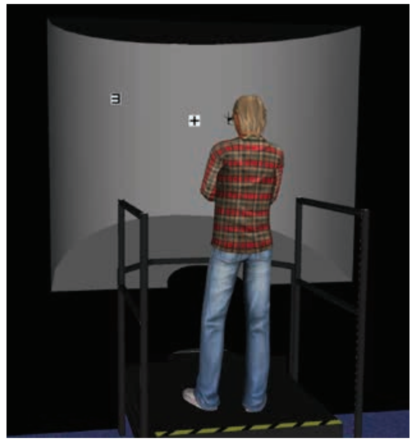
Purpose

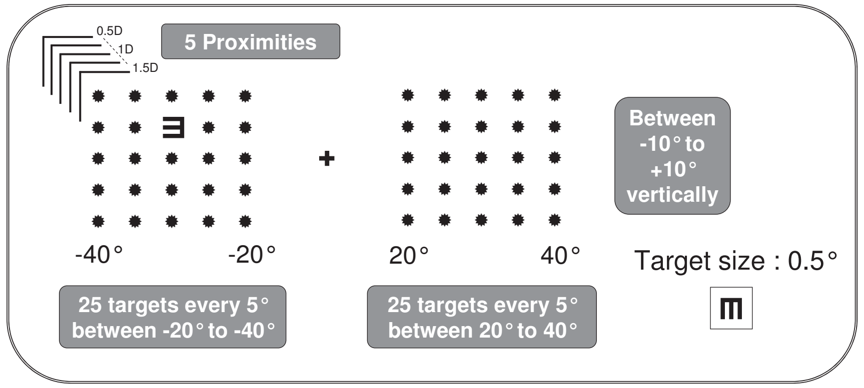
Having a sighting dominant eye is a pledge of efficiency. The sighting dominant eye is privileged by the visual system during motor tasks[1] and will be a directional guide for the other eye. Other results imply that the sighting eye is more sensitive than the other one, or that information from the sighting eye is processed more rapidly[2,3,4,5]. Considering these properties, our hypothesis is that disturbing sighting dominant eye should have a higher effect on visual performance than disturbing the other eye.
The purpose of this experiment was to study the influence of a disturbance of the sighting-dominant eye during a visual detection task involving head movements.

Method



The subject's task was to indicate the E orientation with a joypad

Between each peripheral target, the subject had to fixate a Central Cross Target located in his Straight Ahead Gaze Direction.



0.5D
1D
1.5D
5 Proximities
-40°
-20°
20°
40°
Between -10° to +10° vertically
Target size : 0.5°
25 targets every 5° between -20° to -40°
25 targets every 5° between 20° to 40°

Targets were projected on a stereoscopic display during 1,5 s.

Subjects

4 right sighting-dominant eyes
4 left sighting-dominant eyes

(Hole-in-The-Card Test)

Experimental Conditions

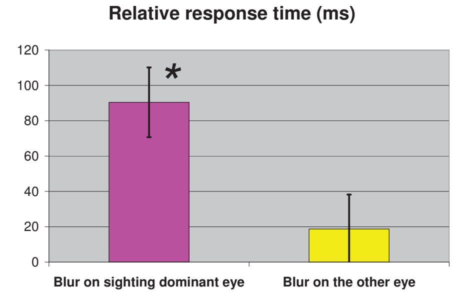
- Control condition : symmetrical Blur of 1D on both eyes *
- Test conditions : Monocular blur of 0.75D over Control condition
  - on Sighting Eye
  - on non-sighting Eye

Order of target display was randomized (randomization includes target's position, orientation and proximity).

We recorded the response time to the visual stimulus (time between the display of the target and the button press) and head movements thanks to an optical tracking system.

* The minimum level of 1D of blur was imposed to induce head movements.

Results



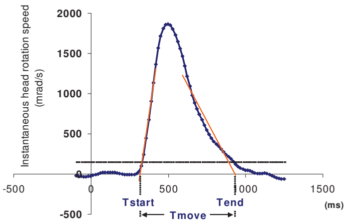
Rmq : Error bars indicate confidence intervals.

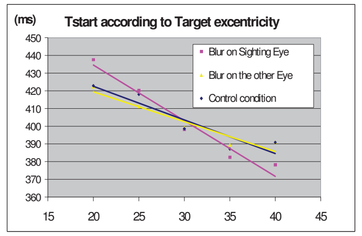
Response time

Data were analysed using ANOVA with repeated measurements.
Response time depends on which eye is blurred.
Relative to the control condition, the average time response increases significantly ($p<0.05$) when the additional blur is on the sighting-dominant eye, whereas it does not change when on the other one (an increase of respectively 90ms vs. 20ms).

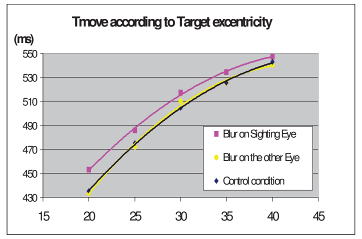
Head movement

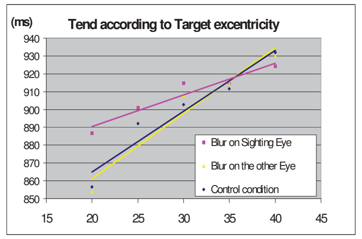
Data were analysed in terms of instantaneous head rotation speed. Acceleration and deceleration phases were linearly fitted to define a start and end time for head movement.





Head movement is slightly longer when the sighting-dominant eye is the most blurred ($p<0.1$). Moreover, the movement duration increases significantly, starting sooner and ending later, with the target eccentricity ($p<0.05$). This behavior is significantly affected by which eye is blurred ($p<0.1$)





No significant difference between the 2 eyes was found neither for time response nor for head movements when analysing against acuity dominance.

Conclusion

Our experiment suggests that the sighting-dominant eye plays a prominent role in time response and head movement profile during recognition task.

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ARVO Annual meeting 2012

The importance of the ophthalmic progressive lens shape on the space perception

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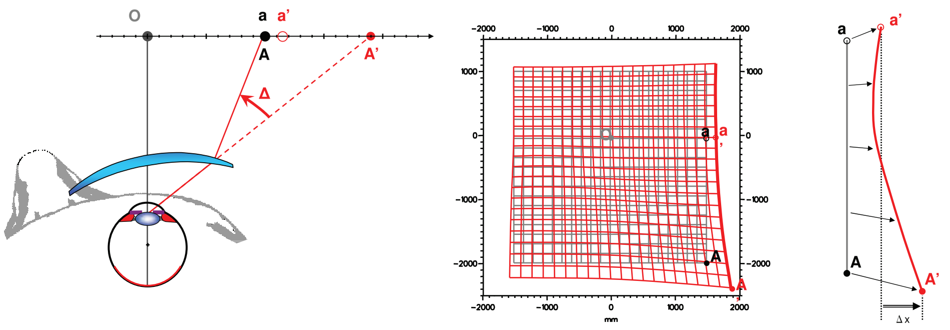
Purpose

Ophthalmic progressive lenses generate space deformation, that is to say distortion of the objects seen through the lens[1]. This is roughly due to power progression in the lens. The most common effect is known as "swim effect" sometimes reported by wearers in binocular and dynamic vision[2,3,4]. It is commonly admitted that these effects are closely linked to the optical properties of the lenses (ie power and aberration repartition), thus establishing a necessary compromise with the fields of vision. The aim of this study was to find and validate experimentally different ways to design an ophthalmic progressive lens in order to minimize space deformation without compromising the fields of vision.

Method

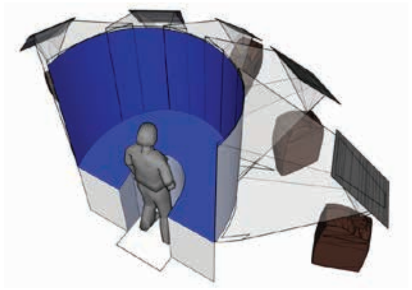
Objective Criteria

Space deformation has been modeled with ray tracing and characterized by optical criteria calculated on distorted grid. We have theoretically evaluated the effects on space deformation for a given design for various geometrical shapes of the lens.



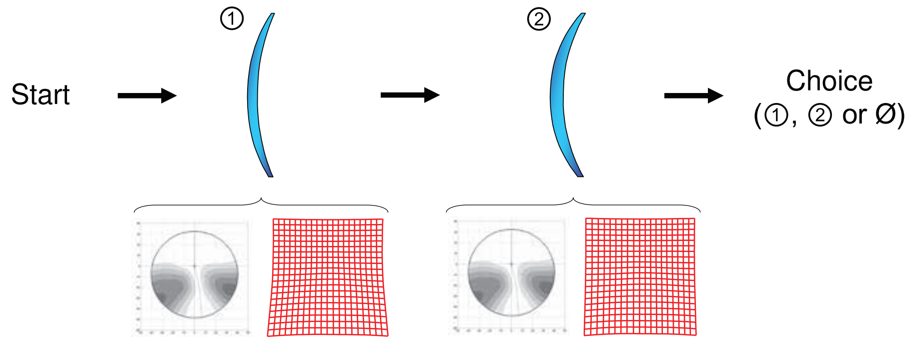
We used a new method of optimization allowing to modify the lens shape while maintaining optical power and aberrations distribution.

Experiment with a virtual lens simulator



Virtual lens simulator allows to simulate the dynamic binocular space deformation seen through virtual lenses in real time when moving the head[5] thanks to stereoscopic display and head tracker.

Ten subjects compared two by two their perception of a grid through different ophthalmic lenses having different geometrical shapes but with exactly the same design, and chose the lens they preferred according to swim effect perception. Presentations were done at random, at least four times per comparison.



Results

We show that it is possible to manage space deformation thanks to the shape of the lens without modifying the power and aberrations distribution.

Lens shape can be optimized to reduce "swim effect"

$$\Delta d = \Delta x / \Delta P$$

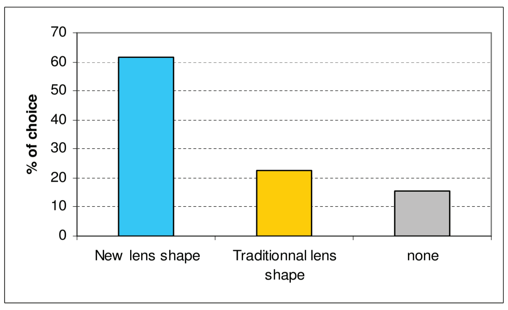
$$Rd = (\Delta d_{①} - \Delta d_{②}) / \Delta d_{②}$$

The objective dynamic space deformation generated by a lens was expressed as the criterion Δd which is the displacement Δx of vertical peripheral object lines divided by the power variation ΔP along this lines. This criteria is relative to the difference in apparent speed of the objects between the upper and lower part of the lens.

The gain Rd of Δd helps to evaluate the performance of lenses having the new optimized shape to reduce "swim effect". It is about 20% compared to a front surface progressive lens, and even more depending on the prescription.

Effect of lens shape on space deformation is perceived

The experimental study shows that the subjects perceived differences in space deformation among the tested lenses. They mostly chose the lenses with the new shape (62%), compared to the classical ones (23%). In 15% of cases, they did not make a choice.



Among cases of choices (less dynamic space deformation perceived), 73% were in favor of the new type of lenses whereas 27% were for front surface progressive lenses.

Conclusion

In this study, we proved the importance of the geometrical shape of ophthalmic progressive lenses for space perception. Moreover we define a new way of optimizing these lenses. This study leads to the design of new types of progressive lenses having advanced shapes minimizing space deformation without compromising the field of vision.

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Poster presented for the first time at European Academy of Optometry and Optics, April 2012" or "Poster presented for the first time at ARVO Annual Meeting, 2012", Simulator image in EAOO poster "Courtesy of Barco" LVAR200984 SHK/ETH 10/12