VARILUX® LENSES TECHNICAL COMPENDIUM

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Varilux Physio Enhanced™: The First Progressive Lens Design to Use Pupil Size Modeling to Improve Vision in Low Light Conditions

James D. Colgain, OD

ABSTRACT Most progressive addition lenses achieve adequate performance under normal daylight (photopic) conditions, but quality of vision declines noticeably in dim (scotopic) light. Increased pupil size in dim light enlarges the beam of light admitted to the eye through the entrance pupil of the optical system. The larger beam diameter also means that light entering the eye has passed through a greater area of the spectacle lens, and accordingly more small optical aberrations in the spectacle lens will affect the light path, diminishing contrast sensitivity and visual performance. To address this problem, vision scientists at Essilor developed an advanced behavioral model that predicts how changes in pupil size will affect lens function, and this data can be incorporated directly into the lens design. The result is the Varilux Physio Enhanced™ lens, an optimized design that achieves excellent performance at all viewing distances under a wider range of lighting conditions—most importantly in low light conditions. This has been confirmed clinically in a double-masked, randomized patient preference study, as well as by comparisons of wavefront aberration levels and modulation transfer function between Varilux Physio Enhanced and other top-tier competitive lenses.

Introduction

Up to now, normal physiological changes in pupil size have imposed limits on progressive lens performance. In healthy eyes, pupil size changes in response to environmental stimuli—dim light and viewing objects at a greater distance both cause pupils to dilate. If the patient is wearing glasses, this increase in pupil size means that the diameter of the beam of light that enters the pupil passes through a correspondingly larger area of the spectacle lens. Since no lens is perfect, as more of the lens surface is used, the visual system will be exposed to more aberrations and suffer a corresponding drop in quality of vision.[1]

This is more than a theoretical problem. For presbyopes, the most common complaint associated with their condition is a need to see better in dim light, particularly for near tasks; and a recent consumer study indicates that spectacle lens wearers want improved performance in low light conditions.[2] To address the problems that pupil size variations pose for progressive lens performance, the Varilux Physio Enhanced™ lens design incorporates advanced computer modeling data to strategically reduce lens aberrations and, thereby, improve visual sharpness and contrast sensitivity at all distances in the full range of lighting conditions.

Factors Affecting Pupil Size and Lens Performance

Pupil size varies depending on several factors, including the level of illumination reaching the retina, the eye's accommodative state, use of some prescription and OTC medications, as well as the patient's age.[3,4] As previously noted, the pupil widens in dim light and when the object of regard is distant; and the pupil constricts in response to bright light or when the eye accommodates to view near objects. Additional studies have shown that older individuals have smaller pupils than younger people, especially under low light conditions. When all is taken into account, healthy human eyes can have pupil sizes ranging from 2 to over 8 mm.

The type of lens required to correct an individual's refractive error also interacts

with pupil size to affect lens performance. Lens power, and whether the lens is converging (plus power) or diverging (minus power), affects the diameter of the beam of light passing through a pupil of a given size. For example, a converging (plus power) lens will expand the beam and diverging lens will narrow it. Thus, the lens power and the pupil size interact to determine the area of the spectacle lens responsible for the wavefront entering the eye.

Further complexity arises because the area on the lens through which gaze is directed is not a static location. As gaze shifts and pupil size changes, different areas of the progressive lens surface come into use. To be able to incorporate this multifaceted understanding of lens-eye interaction into lens design, Essilor took data from thousands of eyes to develop a sophisticated computer model that identifies each possible use area based on illumination level and the patient's age, ametropia, and accommodative state.

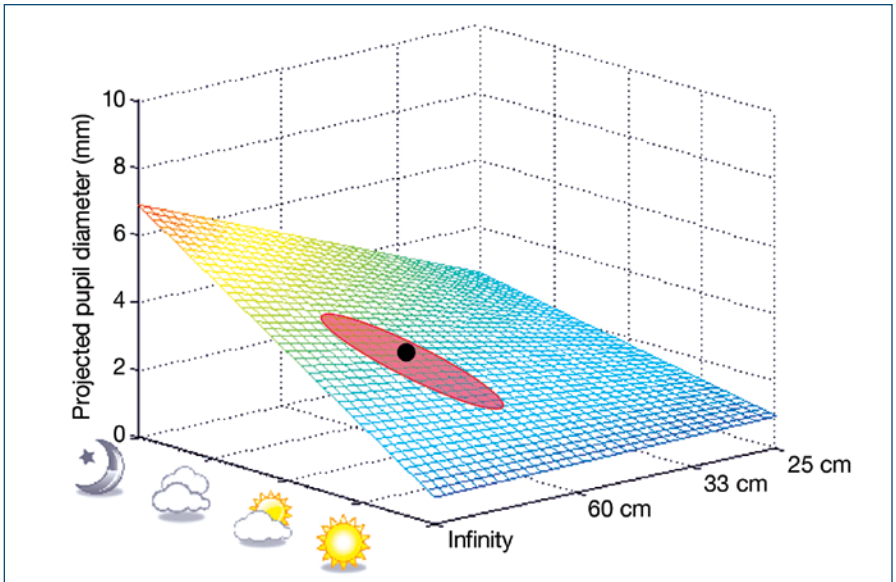

FIGURE 1 The area in red represents the use area of the lens (also called the projected pupil diameter) that corresponds to a maximum probable human pupil size under the specific lighting level and viewing distance combination being modeled. The Rx and add power are also factored into the model, as is the direction of gaze. This represents only one of many such calculations used to design the lens surface.

Advanced Pupil Modeling Optimizes Lens Design

Of the four factors that determine pupil size, ametropia and age are described by traditional lens measurements: the lens Rx describes the ametropia, while ADD power is a reasonable surrogate for age. To address the remaining two factors, illumination level and accommodative state, the computer model predicts pupil size over a range of lighting conditions and viewing distances for a given Rx-and-ADD combination (Figure 1). For each direction of gaze, the model determines the diameters of the possible use areas (on the spectacle lens) by projecting the pupil size for each lighting level/accommodative state combination onto the lens surface.

Because the largest pupil diameters place the greatest constraints on progressive lens performance, these are chosen for every possible direction of gaze. Then, a pupil-adjusted use-area map is developed for the lens surface by identifying the largest likely pupil size for each region on the lens. (Figure 2). This map guides the final lens design.

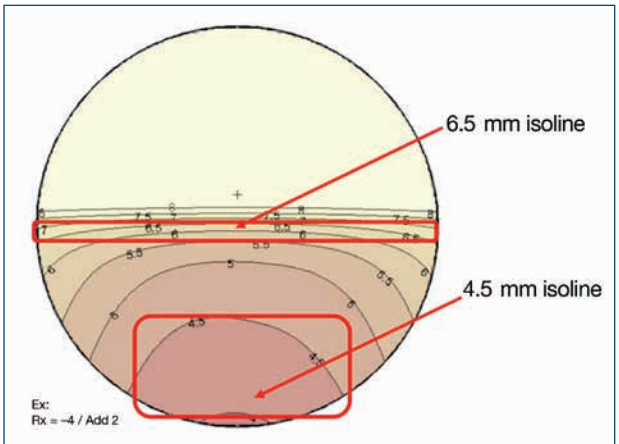

FIGURE 2 For every Rx and add power combination a map is developed that identifies the regions of the lens for which the most constraining (largest) projected pupil diameter is identical. For example, the 6.5 mm and 4.5 mm isolines in the above representation of a –4.00 D lens with 2.00 D add power demarcate the regions for which the respective projected pupil diameters are those that most seriously affect lens performance.

Taking the Varilux® Physio® Design to the Next Level

The basic Varilux® Physio® lens is the product of Essilor's patented W.A.V.E. Technology™; Wavefront Advanced Vision Enhancement, which measures and corrects lens aberrations to optimize optical quality particularly in low light conditions. This improves the wavefront produced by the lens. The computer modeling supporting the design was based on a limited set of three predetermined pupil sizes (4, 5, and 6 mm) for all prescriptions. These calculations also presumed average light conditions and averaged distances for near, intermediate, and far viewing. While this represented a significant advance in progressive lens optics, lens performance outside these parameters did not meet the same visual standards. Thus, while users reported high levels of overall satisfaction, studies indicated that consumers still desired further improvement of vision in low light conditions.

Essilor developed the W.A.V.E. Technology 2™ modeling and design process to address this need. The enhanced behavioral modeling and projected pupil diameter mapping, described in the previous sections of this

TABLE I Patients Preferred the Varilux Physio Enhanced™ Lens

	Varilux Physio Enhanced™	Varilux® Physio®	*P*-value
Standard Lighting (100 cd//m²)	71% (15)	29% (6)	0.08
Dim Lighting (25 cd//m²)	82% (18)	18% (4)	0.006

Note: Results reported for those subjects who indicated a lens preference in either standard (21/30) or dim lighting (22/30) situations.

paper, incorporate a more robust set of variables, and account for a more complex range of lighting conditions, viewing distances, and projected pupil sizes (2-8 mm). The outcome, as demonstrated by both clinical study and optical bench testing, is that wearers of the resulting Varilux Physio Enhanced™ design now experience all the benefits of the original Varilux® Physio® lens over a broader range of use and lighting conditions.

Clinical Outcomes

A double-masked, randomized wearer test was conducted by an independent research group to compare Varilux Physio Enhanced™ to the original Varilux® Physio® progressive addition lens. Researchers enrolled 30 subjects in this non-dispensing trial, which asked patients to evaluate each of the the lenses after performing a series of everyday tasks.

The 30-patient cohort averaged 52.9 years of age with a best-corrected visual acuity of 20/20. Refractive errors ranged from –6.25 to +3.25 D, with up to 2.50 D of cylinder and add powers from 0.75 to 2.75 D. The majority (17) wore progressive lenses as their primary means of correction, while the remainder indicated habitual reliance on single vision lenses (near or distance vision only; 6), contact lenses (5) or no form of correction at all (2). Myopes (21) outnumbered hyperopes (9), and of the 21 patients with astigmatism, 6 had cylindrical errors greater than 1.00 D.

Through random assignment, subjects received identical-looking eyewear with either Varilux Physio Enhanced™ or Varilux® Physio® lenses to start, followed by the other lens design for comparison. Consistent fitting parameters were used throughout. To simulate real world use, patients executed a series of tasks in variable-controlled environments under both standard (100 cd/m²) and dim (25 cd/m²) lighting conditions. The near vision evaluation gauged ease of use, clarity of vision ,and width of field as subjects accessed small-print features on a digital camera, cell phone, and restaurant menu. Likewise, the distance and intermediate vision evaluations measured the same parameters with reading and typing tasks that simulated, respectively, viewing an LCD screen and working in an office setting. The dynamic vision evaluation involved finding and reading items on grocery store shelves and navigating stairs. Patients were asked to state their "global overall preference" in each test environment and in both standard and dim lighting conditions.

Patients Prefer Varilux Physio Enhanced™ Lens

Study subjects universally preferred the Varilux Physio Enhanced™ design over the original Varilux® Physio® lens. Under dim lighting conditions, patient preference achieved statistical significance, with 82% of subjects choosing the Varilux Physio Enhanced™ lens as the best overall performer. Of those who had a preference, 71% favored the Varilux Physio Enhanced™ lens in standard lighting conditions (Table I). This study provides clinical confirmation that the designers of the Varilux Physio Enhanced® lens achieved their aim—to produce a lens design that provides sharper vision in *any* lighting condition.

Researchers also recorded the comments patients made about the two lenses during the study. The most frequently voiced observations referred to the "better sharpness/clarity/focus" experienced with the Varilux Physio Enhanced™ lenses.

Optical Bench Testing Data

Researchers conducted aberrometry comparisons in which the Varilux Physio Enhanced™ lens was tested against four commonly prescribed, upper-tier progressive addition lenses of identical prescription and material. Additionally, a mathematical model gauged the lenses' effect on contrast sensitivity function (CSF) by calculating the modulation transfer function (MTF) under both standard and dim lighting conditions. (MTF is a measure of how effectively a lens transfers the modulation [ie, the contrast between the lightest and darkest portions] of a perceived object. The higher the MTF of the lens, the more faithfully it transfers the

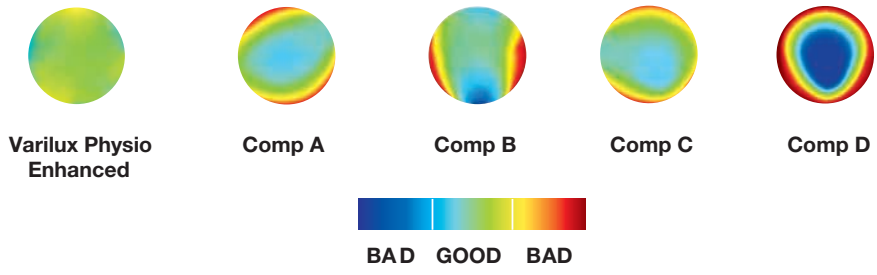

FIGURE 3 The Varilux Physio Enhanced™ design evidenced lower aberration levels than four commonly available, upper tier competitors.

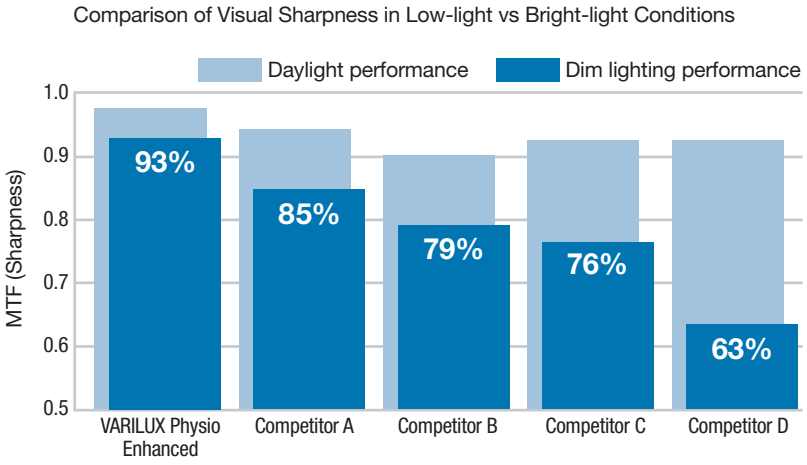

FIGURE 4 **Of the progressive lens designs tested, the Varilux Physio Enhanced lens™ demonstrated the highest modulation transfer function (MTF) for low light conditions. The higher the MTF, the more faithfully the lens preserves image sharpness.**

available contrast detail of viewed objects.)

Reduced Wavefront Aberration Levels, Improved Contrast Function

Of the five lenses, Varilux Physio Enhanced™ demonstrated the lowest aberration levels (Figure 3). Likewise, the MTF omparisons showed that the Varilux Physio Enhanced™ design achieved the highest MTF (93%) in dim light conditions (Figure 4). These optical bench analyses indicate that the Varilux Physio Enhanced product possesses superior optical characteristics, and, as planned, these gains are most pronounced under low light conditions.

CONCLUSIONS

In a double-masked, randomized, independent clinical study, subjects performing real world tasks preferred the Varilux Physio Enhanced™ lens to the original Varilux® Physio® design. The Varilux Physio Enhanced™ lenses were preferred in all lighting conditions, with this preference reaching statistical significance in the dim light. In additional testing, comparative assessments of wavefront aberration levels and MTF demonstrated that the Varilux Physio Enhanced™ lens possesses superior optical characteristics, with lower aberration levels and a higher MTF than four widely available, upper-tier progressive lens designs. These cumulative clinical and bench results indicate that the Varilux Physio Enhanced™ lens provides an improved visual experience for presbyopes at all distances and in an expanded range of lighting conditions. The benefits of this design, which compensates some of the effects of variations in pupil size, illumination levels, accommodative state, and age upon progressive lens performance, are most noticeable under low light conditions. This has important implications for patient satisfaction because, as market data shows, presbyopes rate enhanced sharpness of vision in dim light as one of the performance improvements that they would most like to see in their spectacle lenses.

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VARILUX® X series™

WHITE PAPER
& WEARER
TEST RESULTS

VARILUX® X SERIES™ LENSES

THE MOST ADVANCED VARILUX® LENSES EVER

SÉBASTIEN FRICKER
DR. MARTHA HERNANDEZ-CASTANEDA
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CHARLES LEBRUN
DR. DAMIEN PAILLÉ
BENJAMIN ROUSSEAU

ABSTRACT

When Varilux S Series™ lenses burst onto the scene in 2012, they were the first and only progressive lenses that virtually eliminated "swim" while maintaining a wide field of vision. These extraordinary benefits were possible thanks to two groundbreaking technologies: Nanoptix™ and SynchronEyes™.

Despite these significant advances, lifestyle changes mean that progressive lens wearers have ever evolving needs. The active presbyope is constantly on-the-go and in need of a lens that will keep their vision sharp at all distances, in every situation. To meet this need, Essilor developed Xtend™ Technology to enable wearers to switch between multiple near distances with unprecedented ease.

Essilor's new Varilux® X Series™ lenses build on the groundbreaking innovations of Varilux S Series™ lenses to meet the lifestyle needs of today's progressive lens wearers in ways they have never experienced before.

In the contents of this paper, the reader will see that Varilux® X Series™ lenses clearly deliver on the promise to provide sharper and crisper vision.

Essilor has engineered the Varilux® X Series™ lens to optimize visual performance for tasks within arm's reach. It has developed its Xtend™ Technology to ensure simultaneous vision of multiple near distances. The result is a high level of visual clarity for activities at all distances, whether sitting and reading a book, using multiple digital devices at a time, or shifting vision between distances while driving a vehicle.

Varilux® X Series™ lenses outperform all other premium lenses and provide wearers with the best vision possible at every distance, even in low light, for every activity.

KEYWORDS:

arm's length vision, near vision, multiple near distances, seamless transitions, acuity model, volume of acuity, peripheral vision, premium progressive lens, Varilux® X Series™, Xtend™ Technology, Nanoptix®, SynchronEyes®, simultaneous vision

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I. VISUAL NEEDS & THE LENS/WEARER MODEL

1. MULTIPLE NEAR DISTANCES

For the past two-and-half decades, static situations and reading in seated positions have been the activities studied by research and development professionals and lens manufacturers when optimizing near vision for progressive lenses (Meister, 2006; Cochener, Albou-Ganem & Renard, 2012; Maitenaz & Chauveau, 1999; Miege & Pedrono, 1993; Meslin, 2006).

Varilux Comfort® lenses were optimized according to these methods, with power corresponding to 85 to 100% of the prescribed addition. These values are roughly those needed for reading an A4 sheet of paper at a distance of 16 inches (**FIGURE 1**).

As this conception of near vision is clearly outdated, Essilor R&D has updated it for the digital age by taking into account the many different near tasks and activities that are performed within an arm's length today. In addition to static tasks, wearers today need to be able to multi-task with ease. These varied tasks can be considered to correspond to "multiple near distances".

Varilux® X Series™ lenses are designed to provide simultaneous vision of these multiple near distances between roughly 16 and 28 inches. (**FIGURE 2**). By doing this, Essilor has optimized wearers' vision for multi-tasking within arm's reach.

2. THE VISUAL NEEDS FOR MULTIPLE NEAR DISTANCES

When it comes to near vision, reading is perhaps the most important activity and most demanding in terms of visual performance. It is a central part of our lives in today's society. Not only does it take place in a wide array of environments, with many different types of text and dynamic tasks, but it also requires precise vision and involves accurate eye movements.

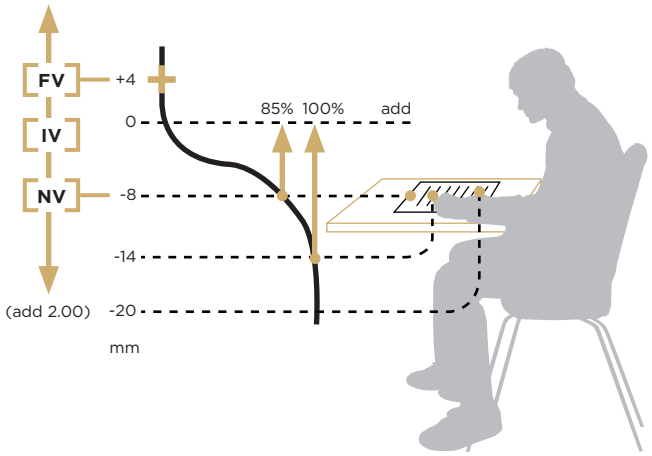
Among other things, it involves perceptual aspects such as letter and word recognition, which are obviously crucial for wearers of progressive lenses.

The reader acquires textual information on several levels: letters, words, and sentences are processed (Perrin, 2015). Visual acuity, as measured by the eye care practitioner (Snellen acuity), is the most important measurement for the reader.

Once the reader recognizes the letter, higher processes involving orthographic and phonological information come into play (Grainger & Ferrand, 1994; Coltheart, Rastle, Perry, Langdon & Ziegler, 2001). Together, they allow the reader to comprehend the elements read.

FIGURE 1. NEAR DISTANCE IN PREVIOUS GENERATION OF PROGRESSIVE LENSES

SINCE THE 90S
A SINGLE NEAR DISTANCE



1 NEAR DISTANCE
1 static plane at 16 in

FIGURE 2. MULTIPLE NEAR DISTANCES WITH VARILUX® X SERIES™ LENSES

2017 VARILUX® X SERIES™ LENS
MULTIPLE NEAR DISTANCES

MULTIPLE NEAR DISTANCES
Sphere within arm's reach

3. VISUAL ACUITY

The eye's ability to perceive and resolve fine details of an object or text is known as visual acuity, and it depends on the clarity of the image projected on the retina. Sharpness of resolution, or Minimum Angle of Resolution (MAR), is commonly used to express visual acuity. MAR represents the minimum angle of separation that enables the eye to distinguish between two distinct objects.

A MAR of 1 arcminute (equal to 1/60 of one degree), which corresponds to 0 LogMAR (i.e. Logarithm of the MAR), is usually considered normal (expressed in feet it equals 20/20 and in meters 6/6). With respect to text and reading, this means the eye is able to make out a letter of which any detail subtends 1 arcminute, assuming the entire letter is five times the size of the detail (**FIGURE 3**).

When reading at a distance of 16 inches, visual acuity of 0.1 LogMAR is sufficient, and at a distance between 20 and 28 in 0.15 LogMAR is enough.

4. ADDITION PRESCRIPTION

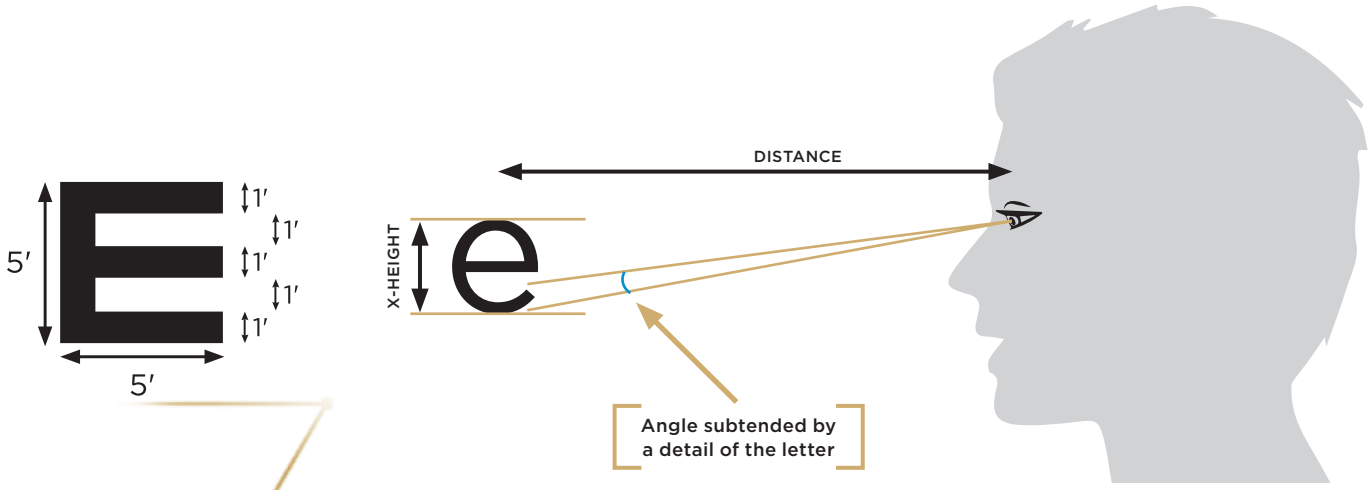
Ametropia must be corrected with the maximum plus for the best acuity. Any undercorrection of hypermetropia or overcorrection of myopia must be avoided so as not to require a higher addition for near vision.

Indeed, the addition prescription is of the utmost importance for visual quality in near vision.

As an individual goes about daily life, their eyes must adapt to the varying distances separating them from objects in their line of sight. This is known as accommodation and allows the eyes to keep objects in sharp focus. Crystalline lens shape modification is the reason for this phenomenon (Millodot, Goumillout & Pouget, 1997).

Addition is the amount of power in diopters (D) that is needed to compensate for a loss of accommodation in near vision. With respect to the latter, this loss typically happens around 40 years of age and results from a hardening of the lens of the eye and its subsequent inability to change shape.

FIGURE 3. MAR FOR VIEWING A LETTER



5. ACUITY MODEL

Essilor has developed a new calculator that is able to manage more complex lens designs. It uses an acuity model to predict the loss – measured in LogMAR – in sharpness of vision when the wearer is looking at a given object through a particular lens. Essilor has perfected its new calculator to take this model into account to generate acuity targets and evaluate the performance of lenses.

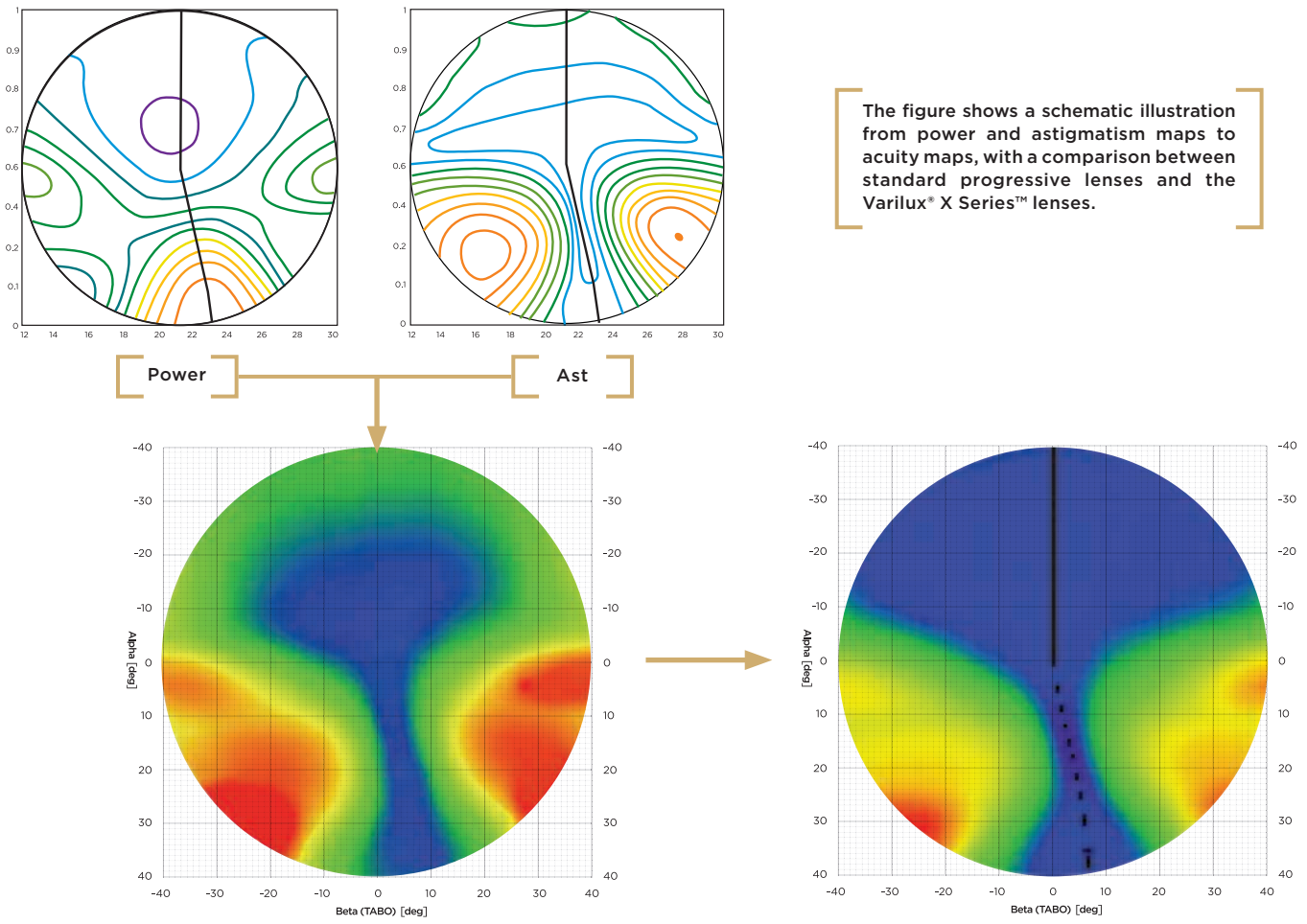
The loss in acuity when a wearer looks through a lens at a given point depends on the following parameters:

- The power of the lens
- The astigmatism of the lens and its axis
- The proximity of the object
- The accommodation of the wearer

In addition to this, the sphere, cylinder, and axis of the lens have a direct impact on the visual acuity performance obtained with the lens (**FIGURE 4**).

The acuity a wearer attains from the use of both eyes is in most cases higher than the best acuity of each eye. This is known as binocular summation and represents a roughly 10% improvement at high contrast.

FIGURE 4. FROM POWER AND ASTIGMATISM MAPS TO ACUITY MAP



The figure shows a schematic illustration from power and astigmatism maps to acuity maps, with a comparison between standard progressive lenses and the Varilux® X Series™ lenses.

Standard progressive lenses

Varilux® X Series™ lenses

II. XTEND™ TECHNOLOGY

1. VISION WITHIN ARM'S REACH

For an individual with a 2.50D addition and no residual accommodation, a distance of 28 inches represents a proximity of 1/0.7, which equals 1.43D. This means about 60% of the total prescribed addition is used for what is generally considered to be in the intermediate vision zone.

The zone of the lens that corresponds to between 60 and 85% of the addition – and is often included in what is referred to as vision within arm's reach – is neither intermediate nor near. This new vision zone complements the typical near vision zone (**FIGURE 5**). As such, it is more and more important in today's digital world, with devices often held within arm's reach.

2. XTEND™ TECHNOLOGY

For a wearer of progressive lenses, visual acuity for multiple near distances is clearly paramount. Simply put, the proper acuity for the different distances will allow the wearer to seamlessly transition from one near distance to another when looking at objects within arm's reach.

To achieve this, Essilor has developed its Xtend™ Technology to greatly enhance the Varilux® X Series™ lens' performance with the multiple near distances – and in particular with vision within arm's reach. It generates uniquely optimized acuity buffers that temper each addition variation to boost depth of field and enhance the local surface shape to widen the acuity volume and provide simultaneous vision of multiple near targets.

By targeting the wearer's acuity value, Xtend™ Technology maintains the highest level of sharpness for each distance and as a result maximizes simultaneous vision of multiple near distances.

FIGURE 5. MULTIPLE NEAR DISTANCE ON AN ACUITY FIELD MAP FOR A -3.00 LENS WITH A 2.00 ADD

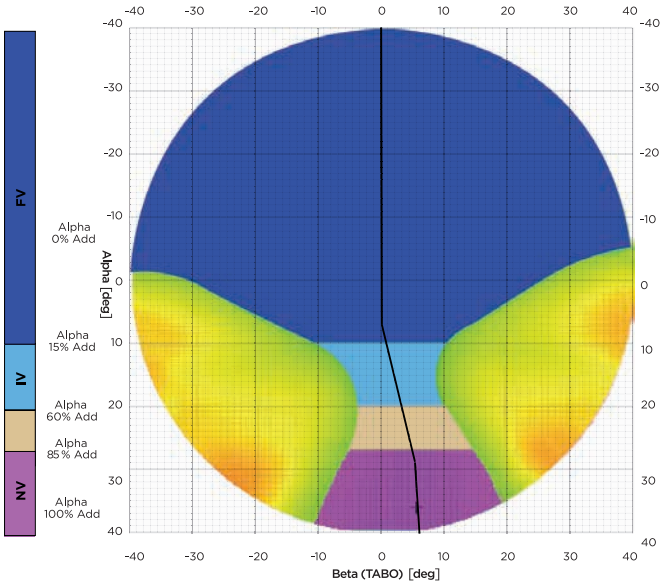
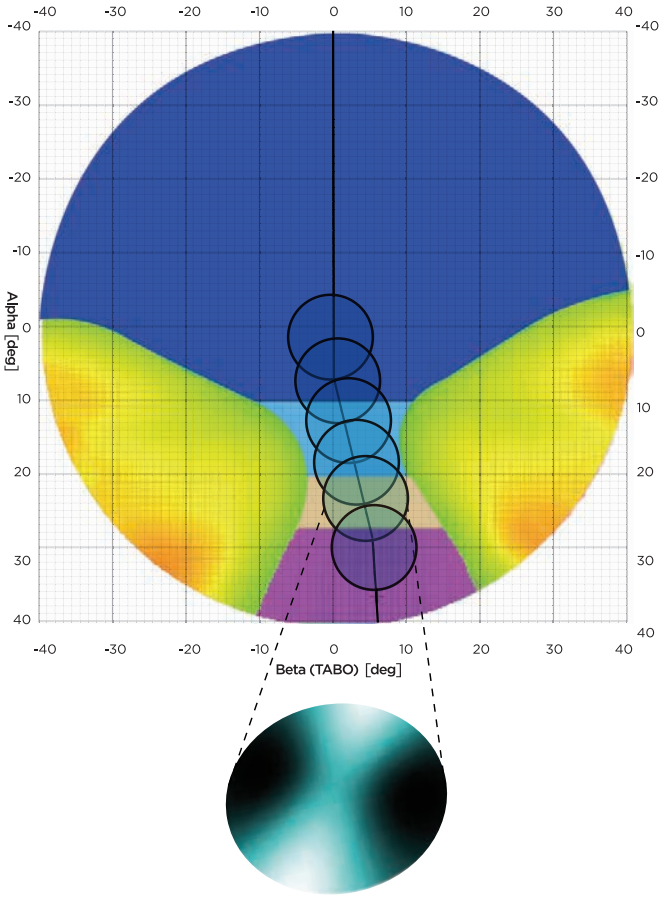


FIGURE 6. THE ACUITY BUFFERS ON THE SURFACE OF A VARILUX® X SERIES™ LENS



FV (Far Vision) represents less than a 15% addition, IV (Intermediate Vision) is between 15 and 60%, Vision within Arm's Reach 60 and 85% and NV (Near Vision) represents an addition from 85 to 100%.

III. THE PERFORMANCE OF THE VARILUX® X SERIES™ LENS

1. OPTICAL PERFORMANCE OF THE LENS

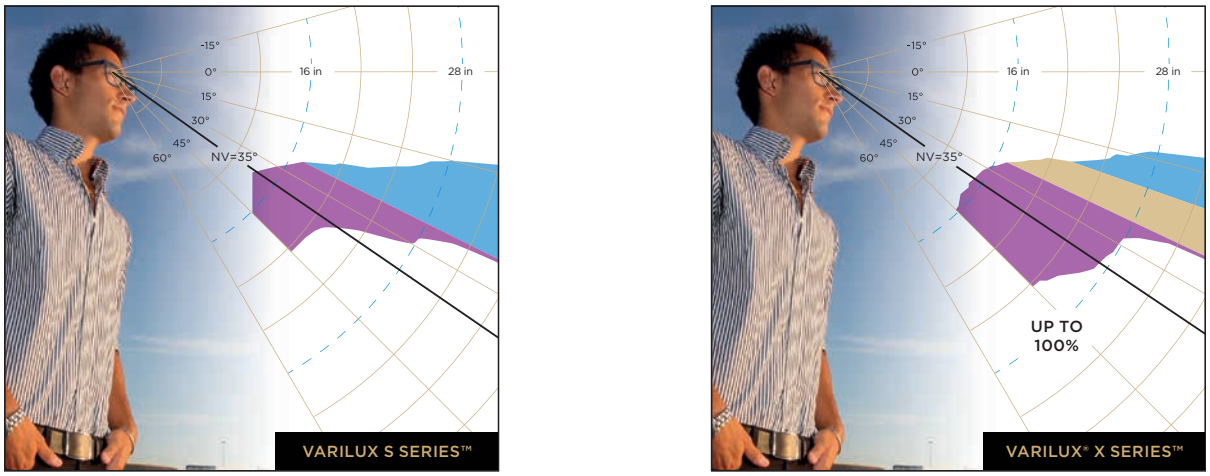
One way of testing the Varilux® X Series™ lens' performance is to calculate the amount of simultaneous vision a wearer needs in relation to the acuity threshold to be able to perform a visual task with a sufficient level of acuity.

As can be seen in the figures below, Xtend™ Technology improves the Varilux® X Series™ lens' performance markedly when the wearer is looking at a particular object.

FIGURES 7 & 8 clearly illustrate increases in both the depth and breadth of the near and intermediate vision zones.

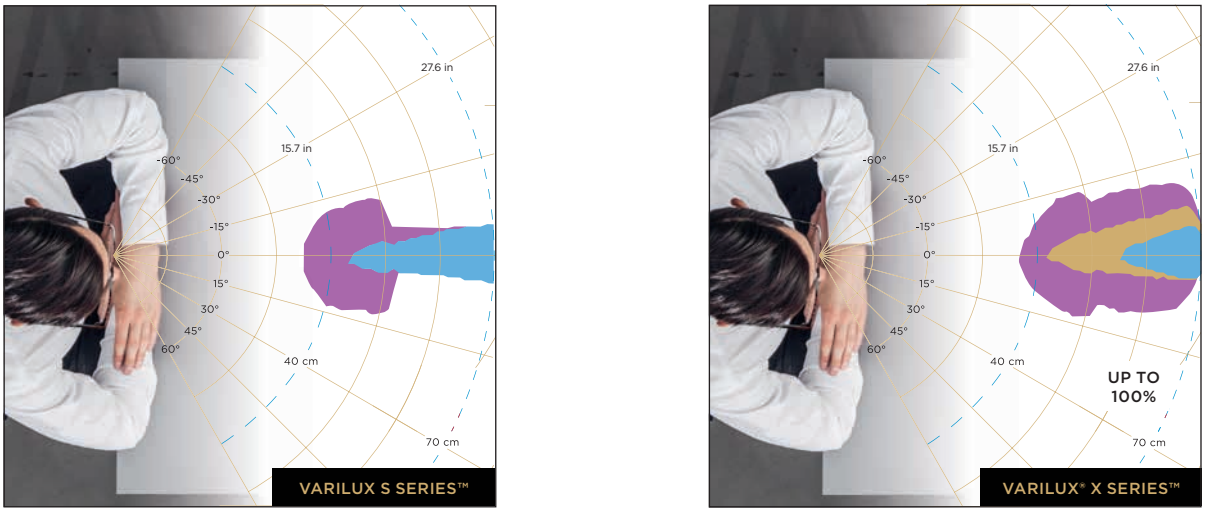
Specifically, Xtend™ Technology maintains a level of near vision acuity above the 0.15 LogMAR threshold, resulting in a longer range of vision and a larger area of sharp sight (**FIGURE 9**).

FIGURE 7. A SIMULTANEOUS VISION COMPARISON OF THE VARILUX S SERIES™ LENS & THE VARILUX® X SERIES™ LENS



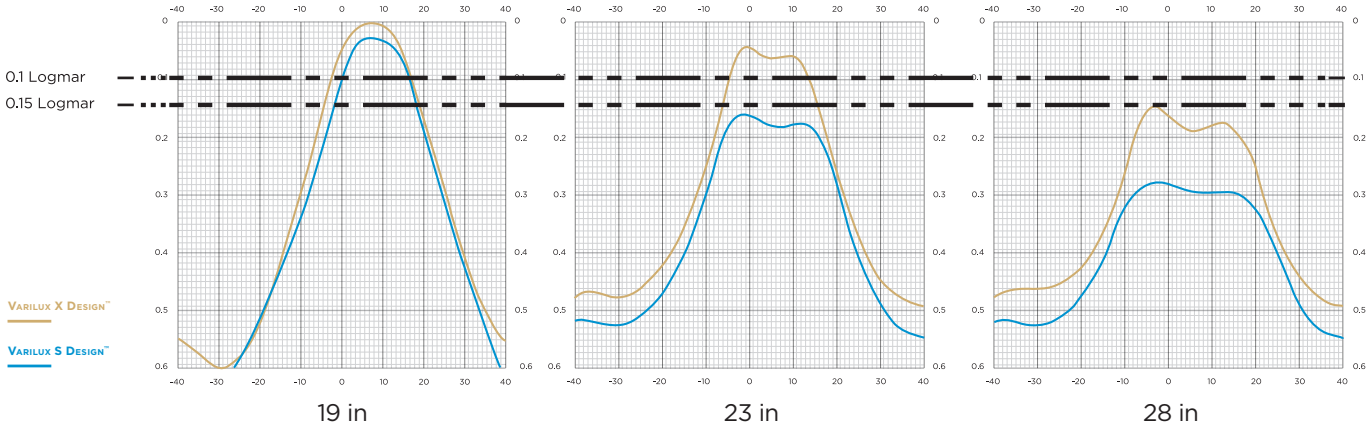
The performance of the Varilux S Series™ lenses (left) is compared to that of the Varilux® X Series™ lenses (right) for a wearer with a -3.00 sph lens with a +2.00 ADD. The purple zone represents near vision up to 20 inches, with an addition above 85%. The blue zone represents intermediate vision. The beige zone for the Varilux® X Series™ lens represents an addition from 60 to 85%.

FIGURE 8. THE SIMULTANEOUS VISION COMPARISON SEEN FROM ABOVE



Figures 7 and 8 illustrate the differences in performance for the same average wearer, characterized by an accommodation model.

FIGURE 9. ACUITY LOSS AS A FUNCTION OF HORIZONTAL FIELD OF VIEW FOR THREE DISTANCES



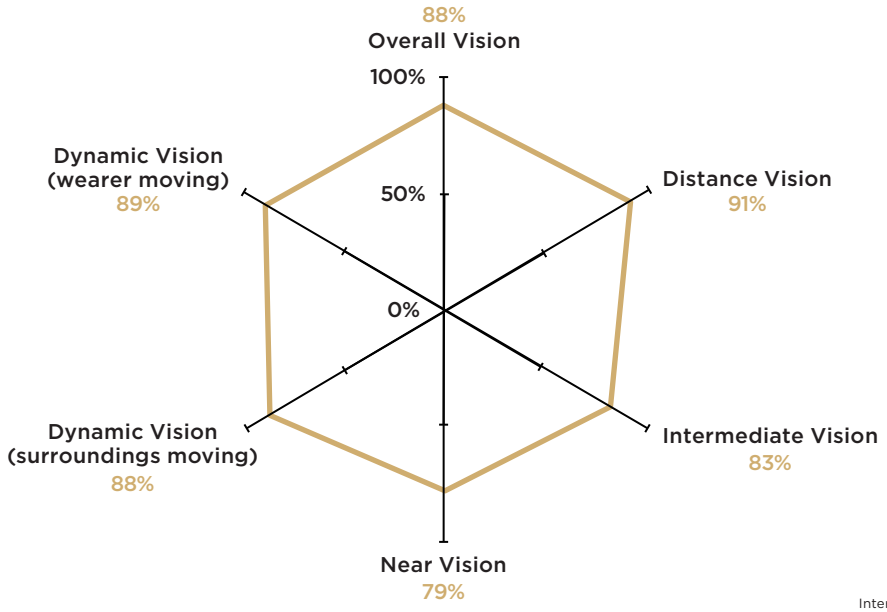
NB: The Varilux S Series™ lenses is compared to the Varilux® X Series™ lenses over three distances for a - 3.00D Addition 2.00 lens.

2. INTERNATIONAL LENS PERFORMANCE & WEARER TESTS

Essilor carried out two studies on Varilux® X Series™ lenses internationally. The first study looked at the overall performance of the lens. As can be seen from **FIGURE 10**, an overwhelming percentage of wearers enjoyed high-quality vision, whatever the distance, intermediate or near. For overall and dynamic vision wearers gave a rating on a 10-point scale from "not clear at all" to "very clear."

With respect to distance, intermediate and near vision wearers gave a rating using the same scale, plus a 10-point scale ranging from "very narrow" to "very wide"; for each distance, the average of the ratings from both scales was calculated to obtain a global visual quality criterion. In both cases 7 to 10 on the scales represented good visual quality.

FIGURE 10. PERCENTAGE OF WEARERS WITH GOOD VISUAL QUALITY WITH THE VARILUX® X DESIGN™ LENS



International multicenter study (n=66)

Wearers also rated their ease of adapting to the lens on a 10-point scale from "very difficult" to "very easy," with 7 to 10 considered the "easy" range. A full 82% of wearers experienced an easy adaptation.

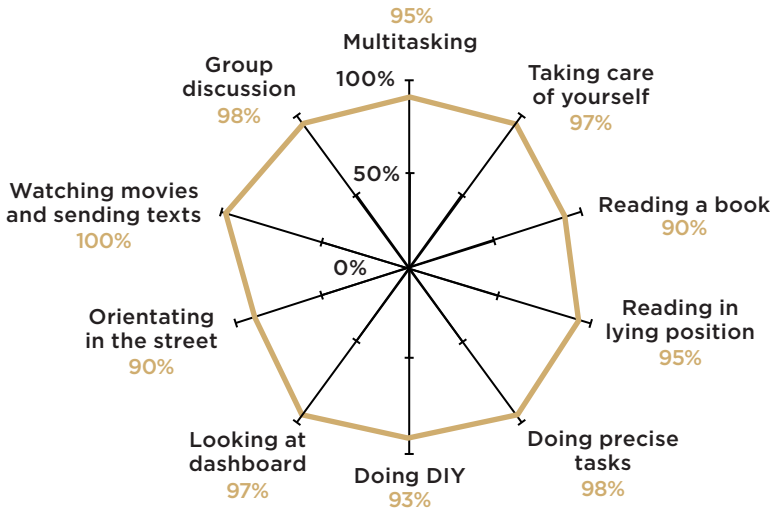
The second study, performed in France, **(FIGURE 11)** looked at the Varilux® X Series™ lens' key benefits, measuring how satisfied wearers were when carrying out activities within arm's reach. Again, they gave a score on a 10-point scale ranging from "not satisfied at all" to "very satisfied", with once again the 7 to 10 range being the overly positive one. The exception was "multitasking," where wearers rated "satisfaction with focus."

Wearers were also asked to rate their head movements needed to see clearly activities carried out at arm's length, choosing from "not at all", "a little," "just right," "too much" and "far too much". The percentage of wearers who needed minimal or no head movements to see clearly was 97% for horizontal vision and 93% for vertical vision.

Both studies then compared the Varilux® X Series™ lenses to Varilux S Series™ lenses. The international study found 65% of wearers had an overall preference for the Varilux® X Series™ lenses over the Varilux S Series™ lenses. In terms of visual quality, using the same scales and criteria, the former had markedly better performance (**FIGURE 12**). The ease of adapting to the lens was also higher for Varilux® X Series™ lenses (82% vs. 76%).

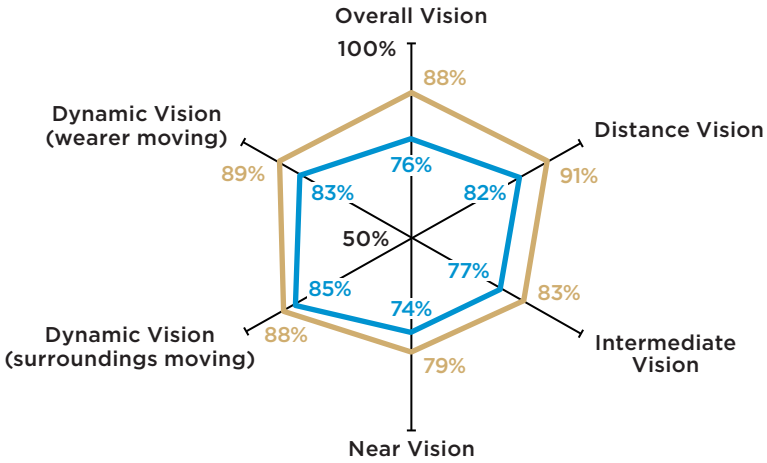
As for their preference for the Varilux® X Series™ lens when it came to multitasking within arm's reach, the French study found no less than 86% of wearers preferred the Varilux® X Series™ lenses over the Varilux S Series™ lenses. A similar preference was found when wearers were asked about which lens they preferred with respect to head movements needed for tasks performed within arm's reach: 74% chose the Varilux® X Series™ lenses over the Varilux S Series™ lenses.

FIGURE 11. SATISFACTION WITH ACTIVITIES WITHIN ARM'S REACH WITH VARILUX® X SERIES™ LENSES



Single-center study - France (n=42)

FIGURE 12. PERCENTAGE OF VARILUX® X SERIES™ LENSES & VARILUX S SERIES™ LENSES WEARERS WITH GOOD VISUAL QUALITY



International multicenter study (n=66)

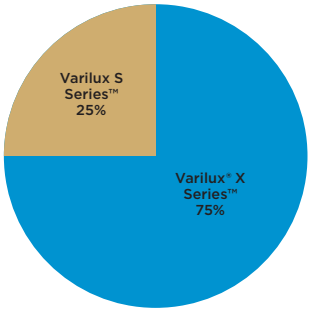
3. DOMESTIC PERFORMANCE & WEARER TESTS

Essilor carried out another study in the United States testing the performance of Varilux® X Series™ lenses against Varilux S Series™ lenses. Wearers were given two pairs of eyeglasses, one with Varilux® X Series™ lenses and one with Varilux S Series™ lenses. The frames, materials, and fitting parameters were all identical. Neither the ECPs who administered the test nor the wearers were told which pairs of glasses had which lenses.

Wearers were then asked to complete a variety of tasks that mimic common daily tasks of progressive lens wearers, including reading and typing text on multiple digital devices and shifting visual focus between distant and near objects while driving. While performing these tasks, wearers were asked to compare the two pairs of lenses in terms of visual clarity, visual field, preference, and satisfaction.

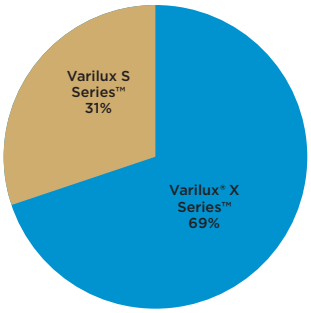
The most remarkable results showed that patients preferred Varilux® X Series™ lenses 3 to 1 over Varilux S Series™ lenses for reducing head movement required to find the "sweet spot" in the lenses **(FIGURE 13)**. Additionally, the study showed that nearly 7 out of 10 wearers preferred Varilux® X Series™ lenses for visual comfort over Varilux S Series™ lenses **(FIGURE 14)** and nearly 8 out of 10 wearers preferred the Varilux® X Series™ lenses for transitioning vision between distances **(FIGURE 15)**. Finally, taking into account all of the activities performed, more than 7 out of 10 wearers preferred Varilux® X Series™ lenses overall over Varilux S Series™ lenses **(FIGURE 16)**.

FIGURE 13: PREFERENCE FOR REDUCING HEAD MOVEMENT



n=52

FIGURE 14: PREFERENCE FOR VISUAL COMFORT



n=52

FIGURE 15: PREFERENCE FOR TRANSITIONING VISION BETWEEN DISTANCES

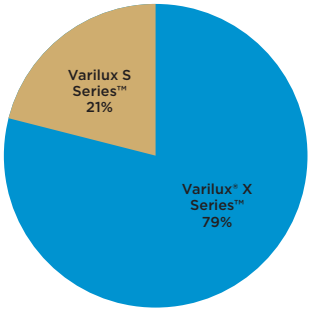


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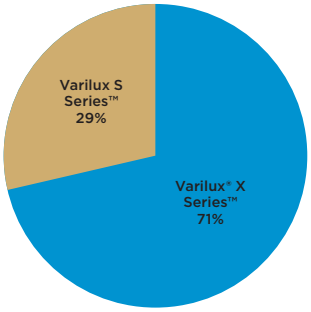
FIGURE 16: OVERALL PREFERENCE



n=52

Key Takeaways:

- Essilor has engineered the world's most advanced premium progressive lens, Varilux® X Series™, to optimize vision within arm's reach (between 16 and 28 inches).
- By developing an advanced calculator, Essilor is now able to manage more complex lens designs and generate acuity targets to optimize the performance of lenses.
- Drawing on its SynchronEyes™ and Nanoptix™ Technologies, Essilor has developed new Xtend™ Technology to greatly enhance the Varilux® X Series™ lenses' performance for visual tasks within arm's reach.
- Xtend™ Technology increases both the depth and breadth of the wearer's simultaneous vision for multiple near distances.
- International Essilor wearer studies evaluating the overall performance of the Varilux® X Series™ lenses revealed that an overwhelming percentage of wearers enjoyed high-quality vision, whatever the distance.
- Additionally, the international wearer study revealed that 95% of wearers were satisfied with the lens when multitasking within arm's reach. Wearers also found that they did not need to move their head horizontally (97%) or vertically (93%) to see clearly with the Varilux® X Series™ lens.
- Studies in the US showed wearers preferred Varilux® X Series™ lenses 3 to 1 over Varilux S Series lenses for reducing head movement required to find the ''sweet spot.''
- Finally, US wearer studies showed that more than 7 out of 10 wearers preferred Varilux® X Series™ lenses over Varilux S Series™ lenses.

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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:

- **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 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.

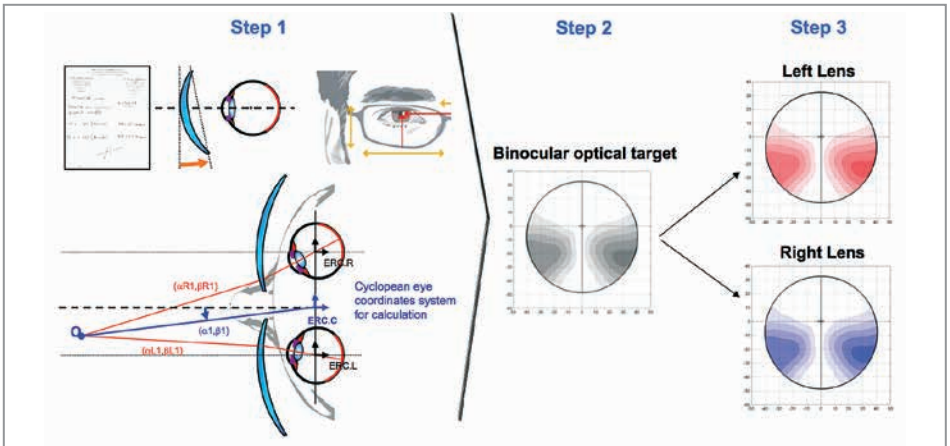

FIGURE 1 Beginning with individual eye parameters, SynchronEyes Technology™ creates a binocular optical system in which optical quality is balanced at homologous points on each lens.

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.

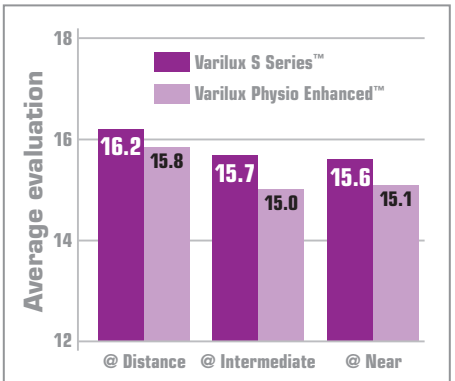

FIGURE 2 In wearer tests, subjects found wider fields of vision at all distances in Varilux S Series™ lenses than in industry-leading Varilux Physio Enhanced™ lenses. (Evaluations based on a 20-point scale.)

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). ■

For additional information:

www.VariluxUSA.com/variluxSSeries – Technical Information

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

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 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.

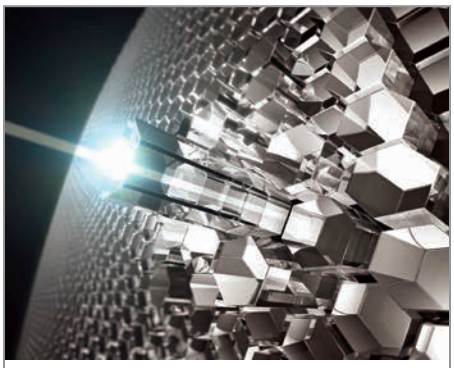

FIGURE 1 Varilux S Series™ lenses are calculated from many tiny optical elements.

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.

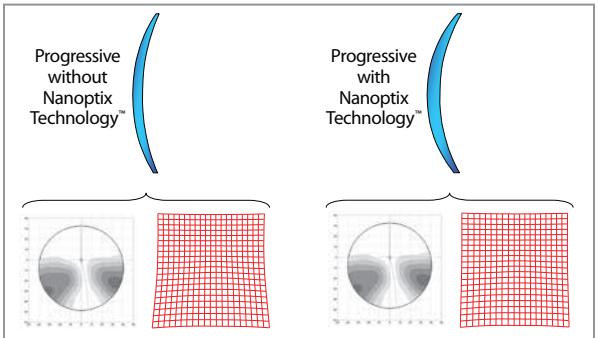

FIGURE 2 Using dynamic vision in a virtual reality environment, subjects compared their perception of a grid as it would appear through a progressive lens either with or without optimization aimed at elimination of "swim." Among subjects with a preference, 73% preferred the optimized design.

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. ■

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:

- **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™.

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™.

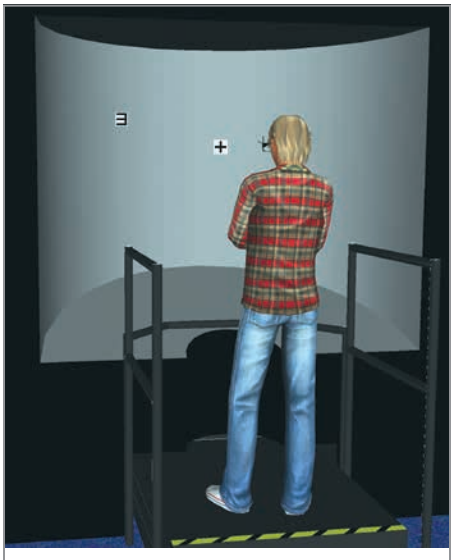

FIGURE 1 Target acquisition test device. Subjects looking straight ahead were shown an off-axis target. Time to start of head movement and target acquisition were measured.

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. ■

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.

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

PATENTS

Varilux® X Series lenses
US Patent Nos. 6,382,789; 7,207,675; 9,454,019; RE42781

Varilux® X FIT™ lens
US Patent Nos. 6,382,789; 7,207,675; 9,454,019; RE42781

Varilux® X Design™ lens
US Patent Nos. 6,382,789; 7,207,675; 9,454,019; RE42781

Varilux® X 4D™ lens
US Patent Nos. 6,382,789; 7,207,675; 9,454,019; RE42781

Varilux® S Series lenses
US Patent Nos. 6,382,789; 7,207,675; 9,454,019; RE42781

Varilux® S 4D™ lens
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Varilux® S FIT™ lens
US Patent Nos. 6,382,789; 7,207,675; 9,454,019; RE42781

Varilux® S Design™ lens
US Patent Nos. 6,382,789; 7,207,675; 9,454,019; RE42781

Varilux® E Series lenses
US Patent Nos. 6,382,789; 7,207,675; 9,454,019; RE42781

Varilux® Physio lens
US Patent Nos. 6,382,789 and 7,207,675; RE42781

Varilux® Physio 2.0 lens
US Patent Nos. 6,382,789; 7,207,675; RE42781

Varilux® Physio 3.0 lens
US Patent Nos. 6,382,789; 7,207,675; RE42781

Varilux® Physio® W3+ eyecode™ lens
US Patent Nos. 6,382,789 and 7,207,675; RE42781

Varilux® Physio® W3+ FIT lens
US Patent Nos. 6,382,789 and 7,207,675; RE42781

Varilux® Physio® W3+ lens
US Patent Nos. 6,382,789 and 7,207,675; RE42781

Varilux Physio DRx™ lens
US Patent Nos. 6,382,789 and 7,207,675; RE42781

Varilux® Physio Short DRx ™ lens
US Patent Nos. 6,382,789 and 7,207,675; RE42781

Varilux Physio Enhanced eyecode™ lens
US Patent Nos. 6,382,789 and 7,207,675; RE42781

Varilux Physio Enhanced FIT™ lens
US Patent Nos. 6,382,789 and 7,207,675; RE42781

Varilux Physio Enhanced Azio™ lens
US Patent Nos. 6,382,789 and 7,207,675; RE42781

Varilux Physio Enhanced India™ lens
US Patent Nos. 6,382,789 and 7,207,675; RE42781

Varilux Physio Enhanced™ lens
US Patent Nos. 6,382,789 and 7,207,675; RE42781

Varilux Physio 360°™ lens
US Patent Nos. 6,382,789 and 7,207,675; RE42781

Varilux® Physio® lens
US Patent Nos. 6,382,789 and 7,207,675; RE42781

Varilux® Physio Short® lens
US Patent Nos. 6,382,789 and 7,207,675; RE42781

Varilux® Comfort 3.0 lens
US Patent No. 6,382,789

Varilux® Comfort 360 New Edition lens
US Patent No. 6,382,789

Varilux® Comfort lens
US Patent No. 6,382,789

Varilux Comfort® W2+ eyecode™ lens
US Patent No. 6,382,789

Varilux Comfort® W2+ lens
US Patent No. 6,382,789

Varilux Comfort DRx™ lens
US Patent No. 6,382,789

Varilux Comfort Short DRx™ lens
US Patent No. 6,382,789

Varilux Comfort Enhanced Fit™ lens
US Patent No. 6,382,789

Varilux Comfort Enhanced™ lens
US Patent No. 6,382,789

Varilux Comfort® lens
US Patent No. 6,382,789

Varilux Comfort Short™ lens
US Patent No. 6,382,789

Varilux® Liberty 3.0 lens
US 6,382,789

Varilux® Liberty New Edition lens
US 6,382,789

Varilux® Ipseo New Edition lens
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