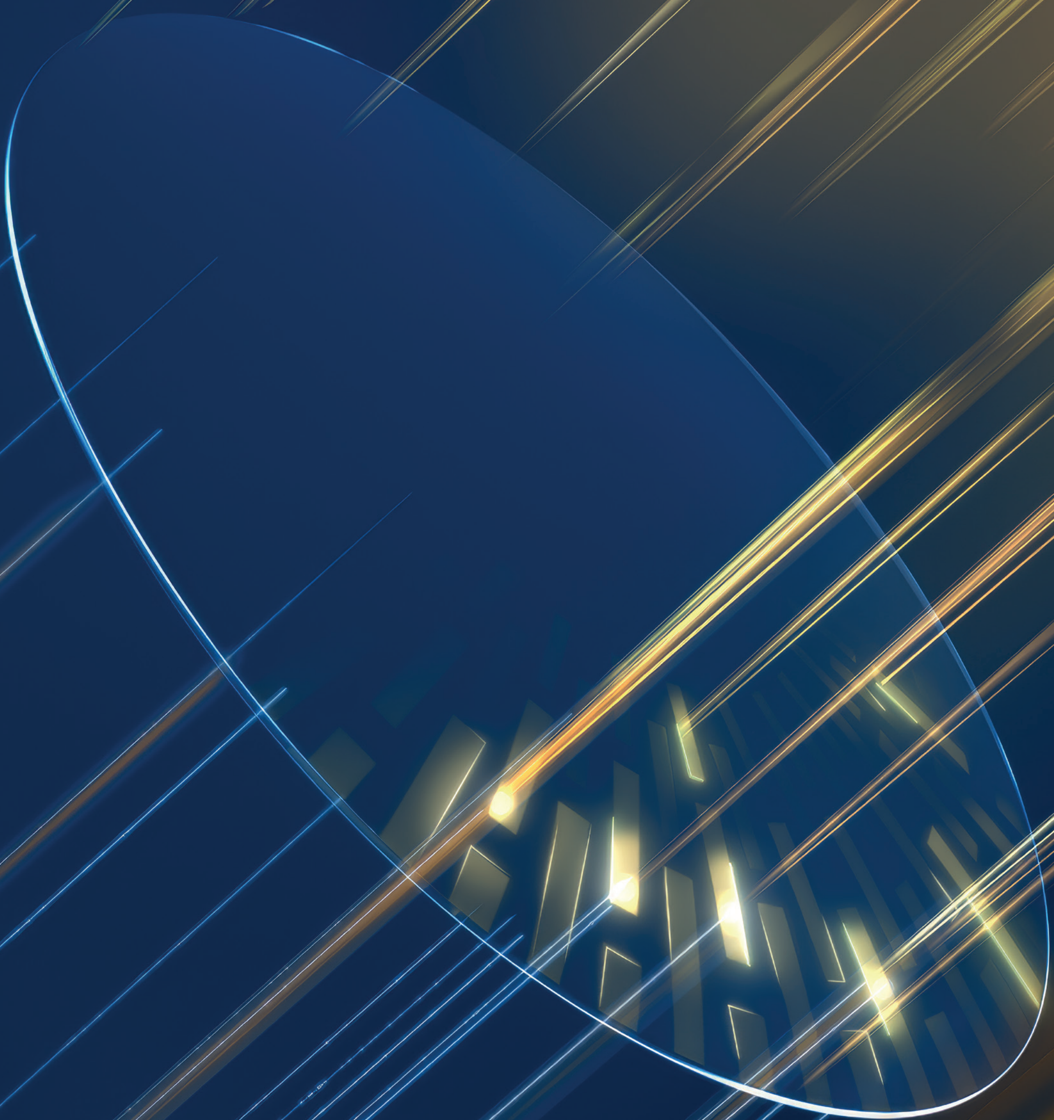
Varilux® Physio® extensee™



Scientific Paper

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evolving vision

Preface

With increasing longevity, most of the population in developed countries will spend roughly half of their lives as presbyopes. As near vision requirements evolve over time for today's presbyopes, so do today's progressive lens designs. Presbyopes are working until later in life, and in many parts of the world, the typical work and home environment is more visually complex and demanding than for previous generations with the almost universal use of digital devices.

Presbyopes are looking for a visual solution which provides them with the best quality of vision, in all conditions, especially in dim lighting, which is one of the pain points of presbyopes.

For progressive lens wearers, the decline in the quality of vision in dim lighting is due to high-order aberrations, specifically coma and trefoil, which cause a decrease in sharpness of the vision and the ability to distinguish objects at low contrast.

Considering **pupil size in lens designs is crucial** so that an optimal optical quality of the retinal image can be attained, and this is conducted by balancing necessary retinal illuminance with optical aberrations and depth of focus. Therefore, **considering the size of the pupil is an essential determinant** for visual performance under changing ambient illumination.

EssilorLuxottica has launched the **next generation of Varilux® lenses: Varilux® Physio® extensee™**.

Only quite recently have vision scientists been able to derive a model taking into account the main four parameters of pupil dynamism. For the first time this AI twinning technology integrates a state-of-the-art dynamic pupil model.

- The Pupilizer™ lens technology **enhances the quality of the wavefront** transmitted through the lens for all gaze directions, taking into consideration the age of the wearer, the distance of the object, the object luminance and the size of the luminous object. Point by point analysis of the combined front and back surface of the lens identifies the high-order aberrations and then each lens is optimized to further reduce the high-order aberrations and provide high vision intensity to the wearer in any light at all distances enhancing the contrast and sharpness.*

- The Dual Booster™ lens surface technology **answers the unmet need of modern presbyopes who still struggle with small letters**, by providing a magnifying effect through the near vision zone without impacting the aesthetics of the lens or the quality of the design.

- Synchroneyes® technology integrates prescription data from both eyes into each lens, **optimizing binocular visual fields and giving wearers expansive vision**.

This paper will review the main aspects of the Varilux® Physio® extensee™ lens, including the Pupillizer™ lens technology and Dual Booster™ lens surface technology, the science behind the lens design, features and benefits.

*Varilux® Physio® extensee™ – in-real life consumer study – Eurosyn – 2024 – France (n=79 progressive lens wearers)

Contents

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1 Introduction

1.1. PRESBYOPIA

In 2024, the British Contact Lens Association (BCLA) released a global consensus report, 'BCLA CLEAR (continued learning evidence-based academic report) Presbyopia', which has provided evidence-based research for clinicians to provide the best patient care around the topic of presbyopia and its management.

A key role of the consensus report was to **adopt a new definition of presbyopia to promote consistency for future research, clinical evaluations and education.**

'Presbyopia occurs when the physiologically normal age-related reduction in the eyes' focusing range reaches a point, when optimally corrected for distance vision, that the clarity and comfort of vision at near is insufficient to satisfy an individual's requirements'.[1]

Presbyopia tends to manifest somewhere between **40 to 45 years of age,**[2] and its expected progression depends on many factors such as habitual working distance, the distance refractive error, illumination conditions and visual needs.

1.2. PREVALENCE AND QUALITY OF LIFE IMPACT

With increasing longevity, most of the population in developed countries will spend roughly half of their lives as presbyopes.[3]

Uncorrected presbyopia can affect quality of life and is a source of significant burden of visual impairment; hence, the treatment of this condition is paramount.[5]

2 The unmet needs of modern presbyopes

2.1. VIEWING HABITS OF MODERN PRESBYOPES

The daily visual demands vary significantly among presbyopes, such as working distances, and different illumination conditions and activities. A study conducted in 2023[6] analysed the daily visual habits of presbyopes. This study revealed that presbyopes are spending more of their time performing tasks in the near and intermediate distance, confirming that working distances may range between 30-40cm to 1m (11.8-15.7 inches to 3.28 feet) depending on their daily activities. Another significant finding from the study highlighted that the time presbyopes spend on their daily visual habits is evenly split between the different luminous conditions: 37% photopic, 33% mesopic, and 29% scotopic. Statistically significant correlations of age with the percentage of time dedicated to activities performed under photopic conditions were found. These correlations indicated a trend of patients dedicating less time performing activities under photopic conditions with increasing age. This may be related to the changes in lifestyle with age, with potentially more time dedicated to activities at home using artificial lights.[6]

2.2. VISUAL NEEDS OF MODERN PRESBYOPES

With presbyopia, many domains of quality of life may be impacted, including difficulty with near vision tasks, such as reading printed text, small print on medicine labels and restaurant menus, using a smartphone or computer or threading a needle.[7, 8]

Difficulty performing these tasks can gradually worsen over time and increase with the severity of presbyopia.[2] These tasks are typically more challenging if the lighting is not optimal.

A recent consensus publication discovered that mild presbyopes may experience tired eyes from near vision tasks or develop headaches or other asthenopias. They may also have difficulty with focusing in dim lighting conditions.[2]

Moderate presbyopes often need brighter lighting conditions in most settings, as well as some sort of reading correction.

Uncorrected presbyopes can manage difficult conditions through various coping strategies, for instance:

Myopes may tend towards self-treating presbyopia by simply removing their glasses to read or increasing their spectacle vertex distance.

As these coping strategies have limitations, progressive lenses are a proven solution to treat the symptoms of presbyopia. Recent research has shown that progressive addition lenses improve quality of life and functional vision for both low and high myopes compared to single-vision distance spectacles.[9]

Figure 1 gives us an overview of the primary near vision function symptoms of phakic presbyopia. This study highlighted that 84% of participants experienced impaired near vision in dim light, such as difficulty reading in low light and seeing close-up in dark environments, and 56% struggled with low contrast sensitivity.

For reading small print, 98% of phakic presbyopes had difficulty with near vision reading. This included difficulty reading printed and handwritten text. The most commonly reported impacts of difficulty reading printed text included difficulty reading menus and difficulty reading labels or ingredients.[10]

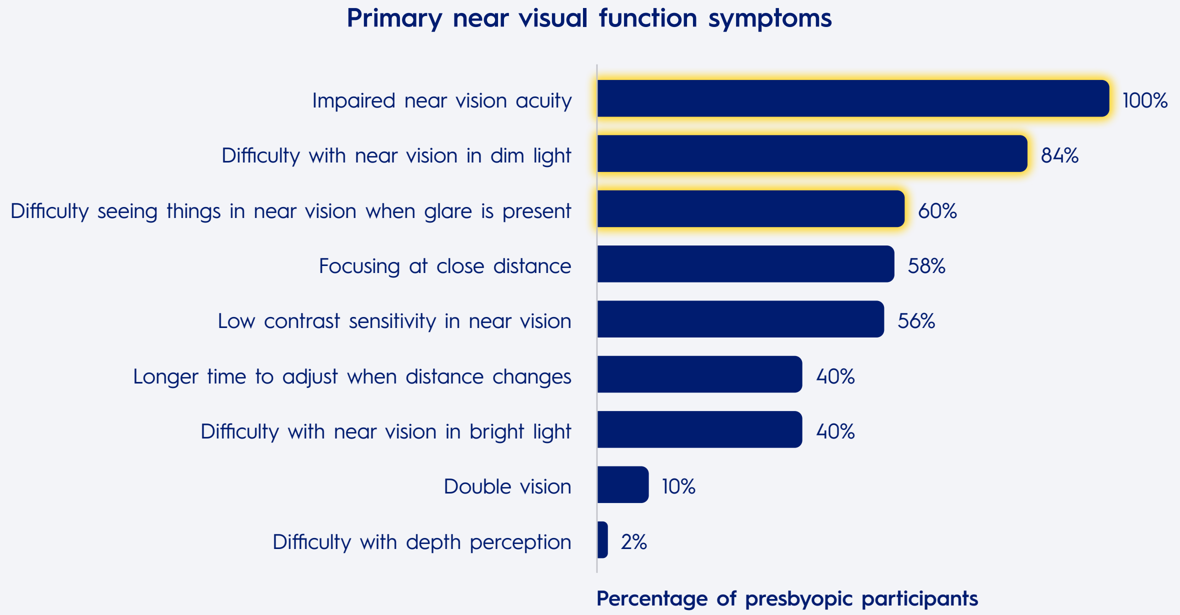

Figure 1: Overview of primary near vision function symptoms reported by individuals with phakic presbyopia[10]

Even with the latest improvements in progressive addition lenses (PAL), presbyopes are still experiencing visual challenges. Today, 39% of PAL wearers are very interested in corrective lenses designed to improve their visual comfort regardless of light intensity, and 41% still have difficulty reading fine print.[11]

3 The scientific background behind the Pupilizer™ lens technology

3.1. DYNAMIC RANGE OF THE HUMAN EYE

The human eye is remarkable in its ability to constantly adjust to a wide range of light levels, allowing us to see in both bright and dark environments. This is referred to as the dynamic range and refers to the range of light to dark that we see at one time. The range of the eye is measured in 'stops' and it is estimated that the human eye clocks around 18-20 stops* of dynamic range, which is equivalent to 1,000,000[12] in terms of light intensity. This means that the eye can perceive differences in brightness of up to a million times between the dimmest and brightest light levels. (darkest tones we perceive at any one time are 1 million times darker than the brightest ones in the same scene).

This dynamic range is achieved thanks to the pupil and retinal adaptation.

3.2. ROLE OF THE RETINA

Part of the eye's large dynamic range is obtained via the retina, which contains multiple types of photoreceptors with different sensitivities.

There are three vision modes depending on the ambient light level: photopic, mesopic and scotopic.

The human eye uses pure scotopic (dark) vision and is rod cell mediated with no colour sensitivity in very low illumination levels. Pure photopic (light) vision is cone cell mediated and provides colour vision in high illumination levels. The vision in between these two ranges is defined as mesopic vision, also known as twilight vision. (Figure 2)

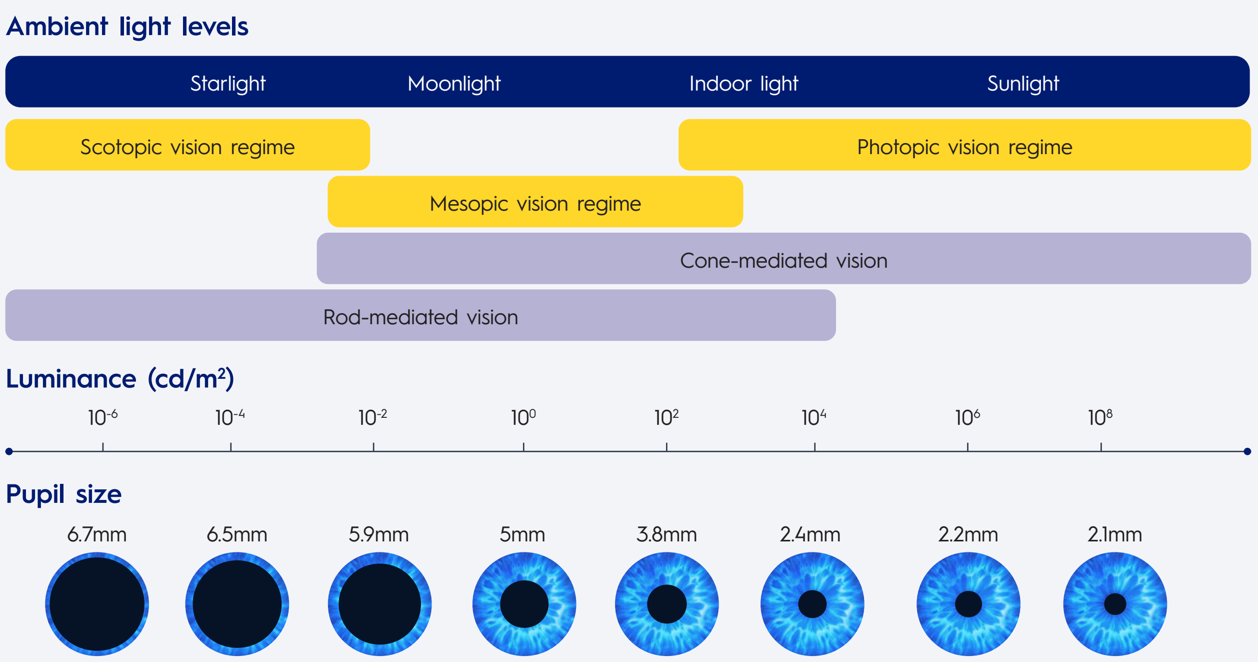

Figure 2: Evolution of the pupil diameter as a function of ambient light levels (Accommodation stimulus = 0D, age 45)

*Increase of one stop equals a doubling of the brightness level

3.3. ROLE OF THE PUPIL

Another contribution to the eye's dynamic range is obtained via the pupil. The pupil is the opening within the iris through which light passes before reaching the lens and being focused onto the retina.[13]

When viewing a scene, our eyes make rapid movements allowing us to measure the light in all parts of the scene, and in a highly contrasted scene the pupil size adjusts based on what the wearer is gazing at. So, the pupil size can change dynamically in a given scene.

Serving as the aperture of the human visual system, the pupil is able to adjust the amount of incident light depending on the ambient lighting level (Figure 2). It is also important to note that the pupil size changes not only affect the amount of light entering the eye, but also impact the amount of diffraction, depth of focus, wavefront and the magnitude of specific aberrations, which are all critical points in attaining an optimal optical quality of the retinal image.

3.4. PUPIL DYNAMICS

The changes of pupil size are involuntary movements controlled by the autonomic nervous system. The range of variation of the pupil size for various conditions and individuals is typically 2mm to 8mm.[14, 15, 16]

The pupil size is generally the same for both eyes. It is considered that when the difference between two eyes is less than 0.5-1.0 mm, it is physiological.

The pupil size is dynamic and highly susceptible to swift alterations due to an array of factors such as:

- **Age**[15]
- **Level of retinal illuminance**[15, 17, 18]
- **Accommodative state of the eye,**[19, 20] **convergence**[19] **& object distance**[14]
- **Sensory and emotional conditions**[21]
- **Ocular pathologies & certain medications**[22]

Of those parameters, the cognitive effects are quite small, and their responses are largely transient.[23]

In the end, the factors that have the biggest influence on pupil size are:

- **Object distance:** The closer the object, the more the pupil size diminishes
- **Luminance:** Pupil diameter increases with decreased luminance
- **Age:** Pupil diameter is smaller in older age groups
- **Ametropia:** The size of the pupil's projection on to the lens varies depending on the local power of the lens
- **Size of the luminous object:** Pupil diameter will be smaller when the object is larger due to emitting more light

The size of the pupil varies dynamically throughout the day to maximize the imaging quality of the eye, under the influence of multiple parameters.

4 High-order aberrations & progressive addition lenses

4.1. WHAT ARE WAVEFRONT ABERRATIONS?

In a perfect optical system (Figure 3a), the rays of light passing through the lens should converge to a single point focus at the retina to create a clear image.

However, in the presence of aberrations within the optical system, (Figure 3b) the rays of light passing through the lens create wavefronts of light which do not converge to a single point focus but instead create a spread of focus, resulting in either a blurred or distorted image.

A real lens does not create a perfectly spherical wavefront. This phenomenon is present in progressive addition lenses. Therefore, aberrations denote the deviation from an ideal wavefront.

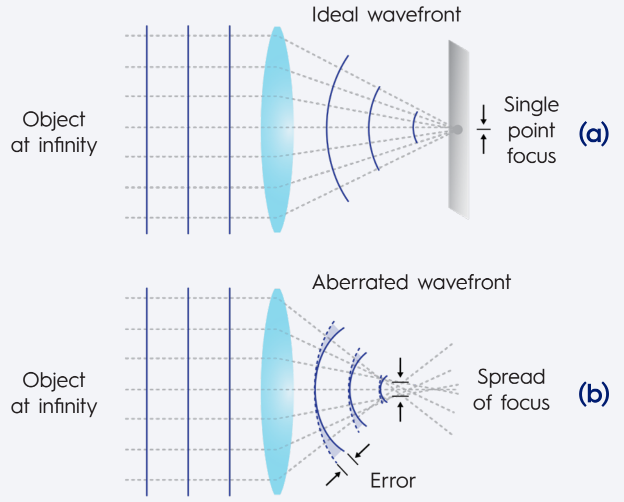

Figure 3: (a) Ideal Wavefront (b) Aberrated Wavefront

4.2. ZERNIKE POLYNOMIALS

There are 2 main categories of light aberrations.

Low-order aberrations, such as power and astigmatism, are responsible for the basic 'refractive errors' of the eye. They produce image blur which increases with both the refractive error and the pupil size. These aberrations are corrected with glasses, contact lenses and surgery.

High-order aberrations consist of more complex deformations of the wavefront and can be identified by the type of distortion acquired from the wavefront of light. These high-order aberrations make up many varieties of aberrations, and the image quality is reduced due to ocular and optical distortions, which are present within the vision correction system.

High-order aberrations include coma, trefoil and spherical aberrations, which all reduce contrast and acuity, just as power error and astigmatism do.

Zernike polynomials are a set of functions (mathematical representations) that can be used to describe wavefront aberrations.

The Zernike wavefront shapes describe the wavefront surface of rays entering/exiting the circular pupil of the eye. These are commonly grouped together in their radial order, which indicates the increasing dependence of the modes on pupil size (Figure 4). For example, the higher the order, the more their effects are dependent on pupil size. High-order aberrations tend to reduce vision quality only when the pupil is large.

Wavefront aberrations can be classified in their Zernike order as;

1. Low-order aberrations (0, 1st and 2nd order)
2. High-order aberrations (3rd, 4th......order)

The Zernike second order aberrations are defocus and astigmatism, and in clinical practice are the most significant and relevant of all the low-order aberrations.

The other components are high-order aberrations with a more complex effect, and these include "trefoil", "coma", "quadrafoil" and "spherical" aberrations, as well as many others.

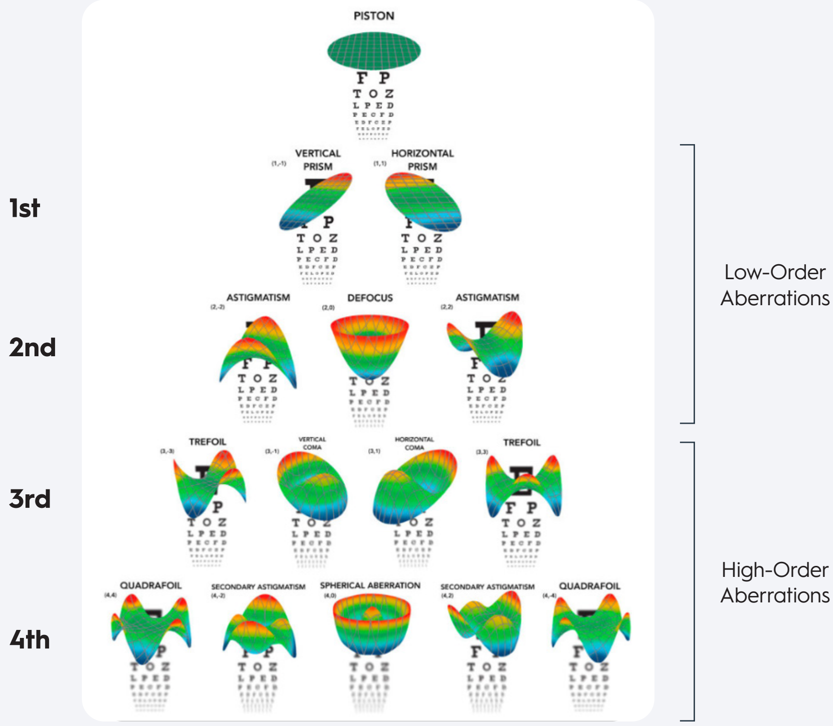

Figure 4: Zernike Polynomials

4.3. STRUCTURE OF A PROGRESSIVE LENS

Progressive addition lenses are designed to provide the desired correction of ametropia for distance and near vision correction by employing a lens surface with a continuously smooth increase in positive focal power.[24]

A smooth continuous surface is achieved by incorporating various amounts of surface astigmatism, located in the lateral regions of the lens surface and generally oriented at an oblique axis. This surface astigmatism varies across the surface of the lens and is virtually zero (depending on the quality of the design) along the progressive corridor.

According to the Minkwitz rule[25], the surface astigmatism changes twice as quickly as the rate of change of power close to the corridor. Therefore, the progression profile of a PAL influences both the variations of power and astigmatism in the lens.

The progressive change in addition power and astigmatism can produce significant levels of certain high-order aberrations, specifically coma and trefoil (Figure 5).

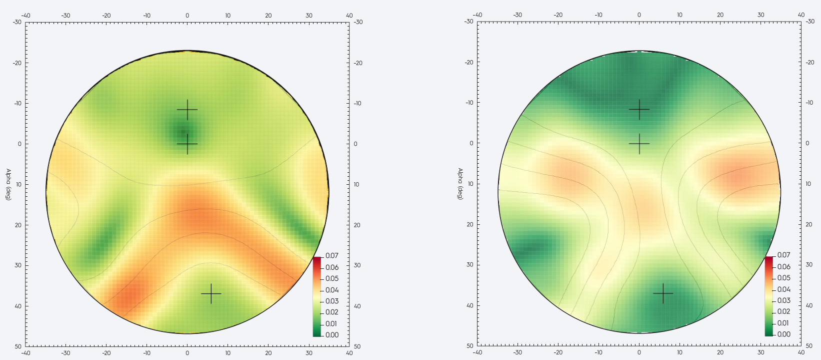

Figure 5: (a) Schematic representation of Coma and mean add power in a progressive addition lens (b) Schematic representation of Trefoil and Astigmatism in a progressive addition lens (-4.00DS, Add+2.00, Pupil Size 4.5mm)

4.4. HIGH-ORDER ABERRATIONS IN PROGRESSIVE LENSES

Progressive lenses possess, by design, variations of power and astigmatism as a function of gaze direction. These variations will induce high-order aberrations in the wavefront when looking through the lens.

As the line of sight of the wearer passes down the progressive corridor of the lens, the refractive power of the lens surface will differ between the upper and lower margins of the pupil. This continuous change in refractive power across the pupil forms a defect in the image, known as coma. 'Coma is directly proportional to the rate of change in mean addition power.'[26]

Trefoil appears where there is a variation of astigmatism. Coma can be expected to have a somewhat greater impact than trefoil on visual acuity.[27]

Due to their specific structure, progressive lenses induce high-order aberrations. These aberrations in progressive lenses can't be eliminated, but they can be managed.

4.5. LINK WITH PUPIL SIZE

The lens performance is traditionally evaluated by ray-tracing near the eye optical axis. This is only an approximation. In reality, for a given object point there is a complete beam of light entering the eye. The extent of the light beam is determined by the size of the pupil (Figure 6). With a beam of light, light usually doesn't focus to a single point. When the pupil diameter increases, the beam passing through the lens (and entering into the eye) is larger. As the lens does not have a single power, the light rays are deviated and admitted into the periphery, and therefore, high-order aberrations become more impactful when pupil diameters increase. The quality of the retinal image is affected by increased aberrations and scattered light.

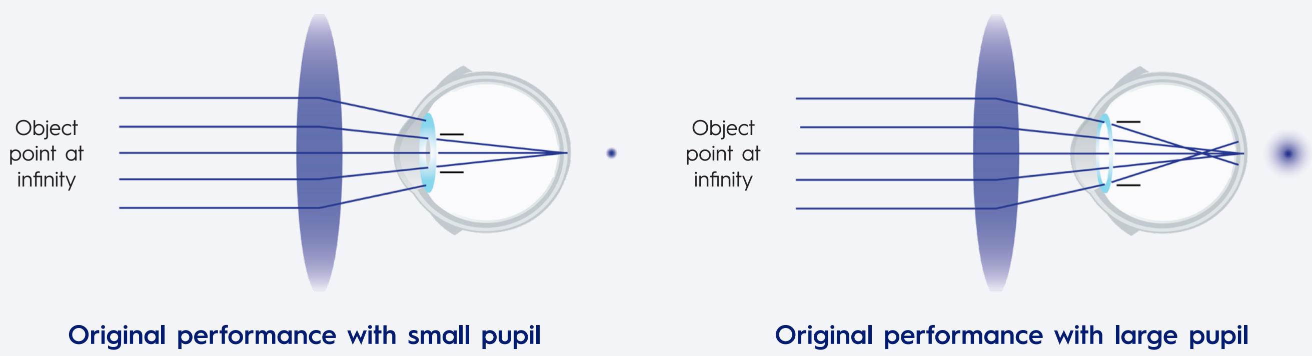

Figure 6: Effect of high-order aberrations and pupil size on the retinal image

In sufficient light conditions, the high-order aberrations of progressive lenses do not impact vision.

The power or astigmatism variation of the progressive lens for a small pupil means that the projected pupil surface is too small to create a noticeable effect on image quality.

But, in low-illuminance conditions where the pupil enlarges, the projected pupil covers a zone of the lens with significantly different power and astigmatism values. High-order aberrations can have a significant impact on vision. For example, increasing pupil size from 3 to 4 mm, a 33% increase, will augment the magnitude of the third-order modes of coma and trefoil by a factor of 2.37.

These aberrations have an impact on the quality of vision. This is why progressive lens designs need to be able to minimize and control the level of aberrations so wearers can benefit from high intensity of vision with contrast and sharpness.

5 Varilux® Physio® extensee™ lens technology

5.1. ARTIFICIAL INTELLIGENCE TWINNING TECHNOLOGY

The Essilor digital twinning technology is an artificial intelligence (AI) system providing a realistic indication of spectacle-wearer perception through lenses by simulating the wearer's experience with their lenses in a 3D environment. This tool allows one to replicate the digital twin of any patient, reproduce daily-life situations and assess the behavior of this humanized digital twin when wearing a specific pair of lenses.

Virtual lens performance simulations are part of a broader lens development process. This methodology, called LiveOptics™, is centered around the lens wearers. It combines simulations with real prototyping and live testing as complementary methods to assess and validate a new design performance.

The AI Twinning technology models the behavior of a wearer performing a visual task:

- Head movements
- Eye movements
- Accommodation
- Pupil size dynamics

The digital twin also comprises perception models that predict the performance of the wearer:

- Sharpness of vision
- Dynamic vision
- Posture

The underlying models are generally based on principles of optics, physiology and perception. In the case where no model already exists, an alternative approach is to create a new model based on measurement data, thanks to artificial intelligence.

Section 3 highlighted the marvel of physiology that is the pupil. By constantly changing its size, it optimizes the image quality of the eye, both in terms of light level and aberrations. To properly evaluate the performance of a lens by simulation, it is necessary to account for the complex pupil dynamics.

For the first time, the AI twinning technology integrates a state-of-the-art dynamic pupil model* that considers all key parameters influencing pupil size: accommodation stimulus, object luminance, wearer's age and the area of the adaptation field, which refers to the object size. More specifically, in binocular conditions, pupil size depends on the product of the object luminance by the object size, a term defined as the effective corneal flux density.[28] This dependency illustrates the fact that the pupil regulates retinal illuminance.

The unified pupil size model is based on data extracted from several studies and scientific publications. Its validity extends to luminance values from 10^{-4} to 10^{4} cd / m^{2}, ages from 20 to 83 years old, field diameter up to 25 degrees and object proximity up to 6D. Its scope largely covers daily-life situations.

5.2. PUPILIZER™ LENS TECHNOLOGY

In order to consider the whole range of situations that a wearer can encounter throughout the day, a number of situations have been defined. These situations include different wearer profiles performing different visual tasks on different objects at different distances, in different light conditions. The new pupil model has allowed us to predict the diameter of the pupil for each gaze direction and therefore consider the wavefront size, in as close as possible to real life conditions according to different prescriptions. Note that the dimension of the beam of light passing through the lens and entering the eye depends on the wearer's pupil size, but also on the power of the lens.

In each situation, the lens performance is evaluated in terms of sharpness and contrast to optimize the lens design, considering the complexity of the pupil size variations mechanism.

These simulations have generated a large amount of data on the quality of vision through a progressive lens design throughout the day. This data has been used to create the Pupilizer™ lens technology.

The Pupilizer™ lens technology analyzes the wavefronts of the light passing through the lens and the pupil of the eye. The process involves identifying high-order aberrations induced by a lens design, prescription and material and then optimizing the design to eliminate or reduce those aberrations that affect visual acuity and quality of vision according to a predicted pupil variation profile.

More specifically, the improvement is obtained via two methods.

1. First, a change of the progression profile between the near vision point and 85% of the prescribed addition diminishes the power and astigmatism variations inside the pupil.
2. Second, an adjusted optical surface has been optimized to further reduce high-order aberrations especially in the near vision zone. This optimization considers the variety of situations to ensure good performance in all light conditions.

How does Pupilizer™ lens technology reduce/minimize high-order aberrations?

Coma is inherently present in progressive addition lenses along the corridor because of the power variation. With the Pupilizer™ lens technology, the aberration maps reveal that coma and trefoil have been minimized in comparison with the Varilux® Physio® W3+ lens, particularly noticeable in pupils greater than 4mm.

*Zapata-Díaz, Juan F., Hema Radhakrishnan, W. Neil Charman, and Norberto López-Gil. "Accommodation and Age-Dependent Eye Model Based on in Vivo Measurements." Journal of Optometry 12, no. 1 (January 2019): 3–13

By analysing the lens performance in a variety of situations, Pupilizer™ lens technology optimizes a corrected optical surface that minimizes high-order aberrations. Pupilizer™ lens technology is fundamentally designed to have better performances in every lighting condition whatever the pupil diameter, but above all, in low light, when the pupil diameter is larger and where the effect of these aberrations is higher.

5.3. DUAL BOOSTER™ LENS SURFACE TECHNOLOGY

The magnification of a spectacle lens is the ratio between the apparent size of an object through the lens and the object's actual size. Magnification is useful for reading fine print because it makes the characters appear larger.

The magnification of a progressive lens depends on two variables:

The first variable is the power of the spectacle lens. The higher the power, the higher the magnification. This must correspond to the wearer's addition power and cannot be modified.

The second variable is the geometrical shape of the lens. The magnification will be dependent here on the surface curvature and thickness of the lens. The magnification is calculated as the ratio of the angular size of the object seen through the lens (dΩ') and that of the object seen without the lens (dΩ) (Figure 7). It is dependent on the power, surface curvature and thickness of the lens. This 2D magnification should not be confused with the angular magnification (calculated as α'/α) being more related to the deviation of light than the change in object size.

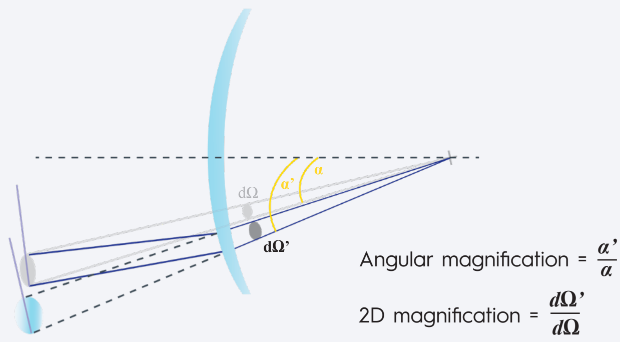

Figure 7: Illustration of the magnification formula.

The Dual Booster™ lens surface technology answers the unmet need of modern presbyopes who still struggle with small letters, by providing a magnifying effect through the near vision zone. The magnification effect has been accomplished with a specific front surface geometry and by distributing the addition power between the front and back surface of the lens (dual-side addition), maintaining the prescribed addition.

If we consider a distance prescription of a -1.00D lens with a 2D addition, the prescribed near-vision power is +1.00D, and this +1.00D power can be achieved by the following:

Full back side lens

Prescription: -1.00 Add +2.00

Dual Booster™ lens surface technology

Prescription: -1.00 Add +2.00

These 2 configurations have the same near vision power of +1.00D, but the second configuration has a higher magnification. This is how lens magnification can be managed by changing the geometry of the spectacle lens.

The level of magnification gain when compared to a back surface progressive lens design is between 0.3% to 2.6%.

Dual Booster™ lens surface technology is designed to bring controlled additional magnification to the near vision zone (thanks to the extra curvature on the front side) while maintaining the lens overall performance to provide a high quality of vision in near vision.

6 Varilux® Physio® extensee™ lens performance evaluation

6.1. PERFORMANCE MEASURES

When choosing the best lenses for the patient, both sharpness and contrast are useful for evaluating the visual performance of the lens. A new criterion named high vision intensity is defined by the combination of high-contrast visual perception and high-level visual sharpness across varying light levels, from high to low light*.

High vision intensity is defined by the combination of high-contrast visual perception and high-level visual sharpness.

Contrast is defined as the ability to distinguish the difference in light intensity between an object and its background.

Sharpness is defined as the ability to distinguish the fine details of an object.

*Without considering the glare effect.

6.2. PERFORMANCE CRITERIA

Simulation results conducted by Research & Development have investigated contrast and sharpness in a variety of settings to show the visual performance of our new Varilux® Physio® extensee™. Contrast has been measured for spatial frequencies ranging from 5 to 30 cycles per degree (cpd), and sharpness has been measured from 25 cpd to 60 cpd.

The simulations evaluated the level of contrast and sharpness that can be perceived over a range of lighting conditions.

+18% of contrast and sharpness enhancement compared to Varilux® Physio® W3+ lens in all light conditions, even in low light*

+25% of contrast and sharpness enhancement compared to similar lenses in the market in all light conditions, even in low light**

Wearers can now access more visual information, enabling them to capture **finer details to see more and enjoy more anytime.**

Similar lenses in the market***

Varilux® Physio® extensee™ lens***

*Simulations vs Varilux® Physio® W3+ – done with AI twinning technology during activities in near vision in various luminance – Comparison between mean's value based on several prescriptions & materials weighted by WW sales – Internal R&D simulations – 2024
**Simulations vs relevant progressive lens products – done with AI twinning technology during activities in near vision in various luminance – Comparison between mean's value based on several prescriptions & materials – Internal R&D simulations – 2024
***For illustration purposes only

6.3. WEARER TEST

In an independent study, 79 progressive lens wearers—fitted with prescriptions identical to their previous lenses — evaluated Varilux® Physio® extensee™ lenses in their daily lives.

*Varilux® Physio® extensee™ - in-real life consumer study - Eurosyn - 2024 - France (n=79 progressive lens wearers)
**Varilux® Physio® extensee™ - in-real life consumer study - Eurosyn - 2024 - France (n=60 progressive lens wearers). Claim applies to Varilux® Physio® extensee™ and Varilux® Physio® extensee™ track, with Dual Booster™. Does NOT apply to Varilux® Physio® extensee™ Classic Edition.

Conclusion

Progressive lens wearers are looking for a visual solution to improve their vision comfort in various lighting conditions, especially at near. NEW Varilux® Physio® extensee™ lenses integrate Pupilizer™ lens technology, a new Dual Booster™ lens surface technology and Synchroneyes® technology™. AI twinning simulations as well as real-life tests have shown that NEW Varilux® Physio® extensee™ lenses provide extra visual sharpness and contrast in any lighting condition, which means PAL wearers will benefit from high vision intensity throughout the day.

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