Varilux S series, breaking the limits

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Performances of progressive lenses have improved a lot from the first generations launched more than 50 years ago. Nevertheless, there are still some limitations considered as inherent to the very concept of power variation of the progressive lenses surface.

Flawless vision should be simple. Yet, wearers still encounter some limits with their premium progressive lenses such as: "I feel wary when going down the stairs", "When moving my head, I feel everything moves and yet nothing should move", "I need to constantly move my head to target what I am looking at".
These limits are due to the fact that progressive lenses are based on a compromise between large fields of vision and limited swim effect. Very few articles can be found dealing with the link between field of vision and distortion and are only valid on a very limited scope [1], [2].

In-Lab analysis on main premium lenses of the market show that each manufacturer manages this compromise differently (Figure 1):
- Either the lenses provide large fields of vision, but higher swim effect
- Or lenses provide reduced swim effect, but narrower fields of vision.

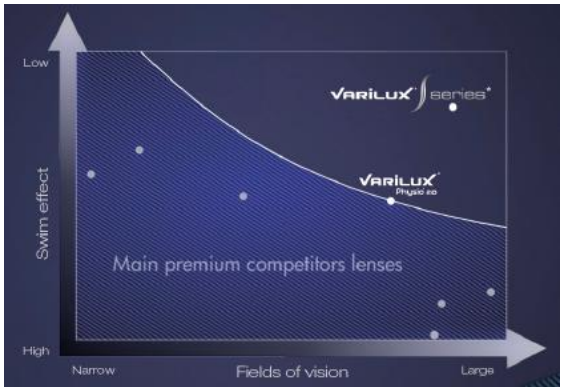


Figure 1: In-Lab R&D measurements of Varilux and main premium competitors[1]

From an historical view, designs coming from far East were relatively "soft" with limited fields exempt from aberrations. Unlike the designs from the Anglo-Saxon part of the world which are paying more attention to fields of vision at the cost of relatively high level of swimming effect.

Based on the most sophisticated progress in optics and knowledge of wearer physiology, and thanks to 11 new patents, Essilor breaks this progressive lenses compromise with the Varilux S series introduction.

Varilux S series breaks the compromise with two exclusive technologies :
- Nanoptix, a revolution in lens technology, virtually eliminating swim effect for a better equilibrium in motion.
- SynchronEyes, a revolution in lens design, optimizing binocular fields of vision for wide angle vision.

This article first details scientific background at the heart of each of these two technologies, and concludes through Varilux S series wearer tests.

1- Nanoptix™, the revolution in lens technology

Distorsion and swim effect definition

Wearers most often relate their swim effect experience with Progressive Addition Lenses when going down the stairs : « I feel wary when going down the stairs ».

Technically, this swim effect results from progressive lenses perturbations on space perception. These perturbations occur first in static vision, when the wearer and surrounding environment are motionless: images appear sharp but distorted. Wearers express for instance that « Straight lines look curved ». Swim effect appears in dynamic vision, when the wearer or his surrounding environment starts moving: the distortion of the image varies in the field of view depending on movements. Wearer relates that when moving his head, he feels everything moves, yet nothing should move.

Both static and dynamic defects impact wearer perception.

In static monocular vision, literature relates several impacts of distortion :
- Images are magnified: depending on the power of the lens, objects are perceived as smaller (negative lenses) or bigger (positive lenses) by the wearer [3].
- Straight lines are perceived curved [4]. This effect can be particularly aggravating with Progressive Addition Lenses: a study conducted by Faubert and al. [5] showed that sensitivity to curvature of a line is higher in the inferior visual field than in the upper visual field.
- The distorted geometry of the image disturbs the static monocular indices of perspective, typically those which allow an observer to perceive the inclination of a plane : for instance with a progressive addition lens, the perspective and depth perception can be modified because objects seen through the bottom of the lens appear nearer than objects seen through the top of lens.

But the dynamic binocular effects of distortion, called « swim effect » are considered by wearers as more inconvenient than effects observed in static situation because objects seem to move unnaturally in the visual field :
- This swim effect can be the cause of adaptation issues.
- It can also lead to postural instability.

This has been demonstrated through an experiment conducted by Faubert and Allard [6] using a visual virtual simulator figure 2). This simulator allows to create a complete 3D environment in order to study the dynamic effects of distortion: a visual variable distortion (which amplitude can be controlled) is presented to a subject who is equipped with 2 trackers to measure his posture (located on his head and his back); results show that postural instability increases dramatically with the amplitude of the variable distortion (figure 2).

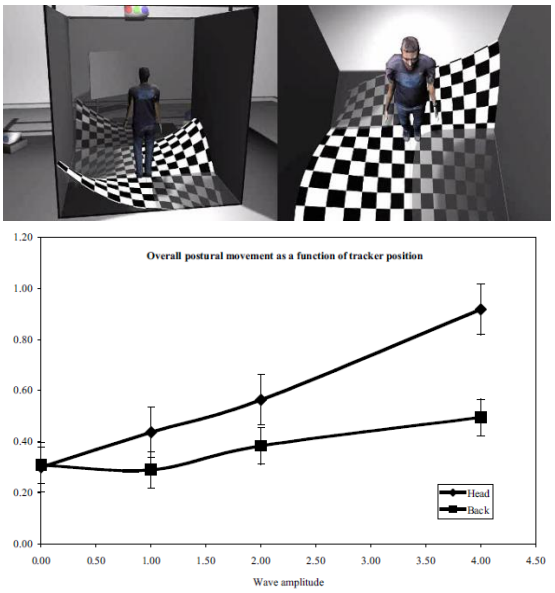


Figure 2. Faubert J., Allard R. (2004). "Effect of visual distortion on postural balance in a full immersion stereoscopic environment".

- In more extreme cases, swim effect can even lead to motion sickness, vertigos or nauseas. These adverse events are caused by the conflict between vestibular and oculo-motor systems. Indeed, there is a shift between the environment displacement seen by the subject and the real environment displacement perceived through the vestibular system.

Why do Progressive Addition Lenses induce swim effect ?

A lens generates rays or prismatic deviations :
-In static central vision, ray deviation makes objects « appear » delocalized (figure 3)
- In static peripheral vision, rays deviation varies with gaze direction: each object point of a given field of view appears with its own « delocalization, and image is perceived distorted.

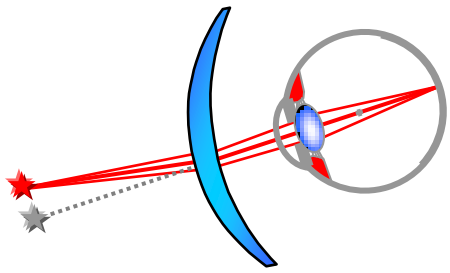


Figure 3 : In static central vision, ray deviation makes objects « appear » delocalized

- In dynamic vision, this leads to swim effect which can be simulated through real ray tracing (figure 4) : the wearer is looking in central vision at the point O of the grid and perceives other points of the grid through his peripheral vision; each peripheral point B of the initial grey grid is seen as coming from B', due to ray deviation D generated by the lens. As a whole, for all gaze directions, for a progressive lens, ray tracing shows that the grey grid is seen as coming from the red grid (Figure 5). Deviation variations between upper and lower parts of a progressive lens induce inhomogeneous image distortion.

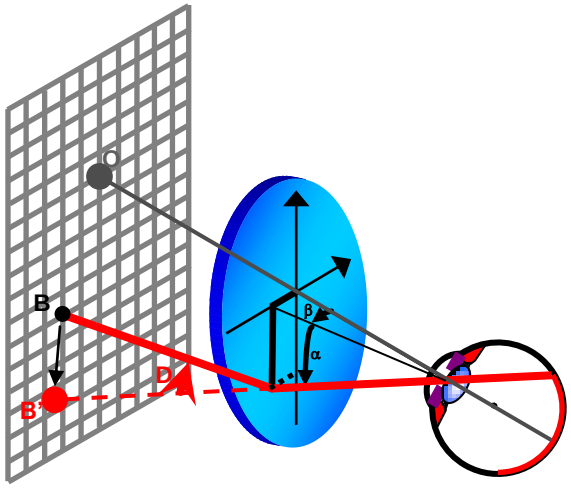


Figure : ray deviation simulation with ray tracing

A step further, ray deviation can also be simulated through real ray tracing when the wearer is moving his head : the wearer keeps looking in the central direction at the point O of the grid; each peripheral line AB of the initial grey grid is seen as coming from A'B' : but with head movement, A'B' moves. And as a whole, the red grid seems to move unnaturally in the visual field. This leads to swim effect.

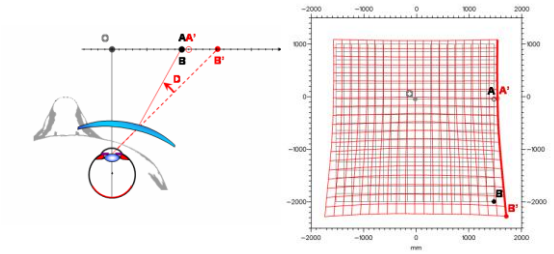


Figure 5 : ray deviation simulation in dynamic vision.

Current levers to reduce swim effect

In first approximation, according to Prentice Law, ray deviation depends on gaze eccentricity and local power: ray deviation increases when gaze eccentricity and/or power increases. As a consequence, Prentice law derivation further shows that deviation variation depends on power variation, therefore on optical design : the higher the power variation, the higher the deviation variation. A first lever to reduce ray deviation variation and swim effect is to reduce the power variation, that is to say to soften the lens design. However managing the swim effect through softening of the design also leads to reduced fields of vision.

The classical Prentice law is only an approximation. To be more correct, it should be completed with a term linked to the lens shape including local front side curvature as well as thickness and vertex distance.

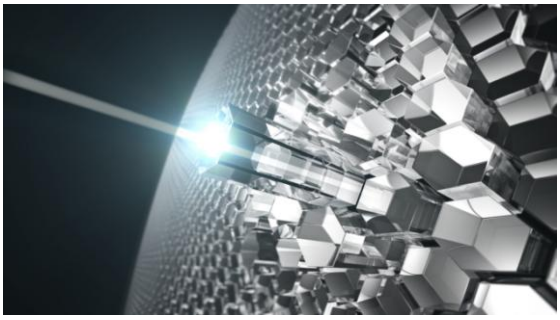
$$\Delta D \sim f(\Delta P, \Delta\gamma)$$

D : ray deviation
P : local power
γ : local bending

By optimizing these parameters, it is thus possible to reduce deviation variation, while preserving the power distribution, the optical design over the lens.

Nanoptix calculation leading to an exclusive geometry

Nanoptix entirely reengineers the fundamental structure of the lenses during their calculation, opening up new degrees of freedom in swim effect management. Instead of considering the lens as a whole shape, Varilux S series is the first lens to be calculated from thousands of tiny virtual elements.



During Varilux S series calculation, length and position of each element is optimized :
- Each element length is calculated to correspond to the required local optical design and power suitable for a given wearer.
- Each element position is calculated to match to the required local lens shape.
- Element by element, the lens is getting built before interpolation step to ensure continuity of the lens at the end of the calculation process.

Lets compare Varilux S series with a standard progressive lens (Figure 6):
- A standard lens is calculated as a whole : the base curve of the lens and the power increase simultaneously between Far Vision and Near Vision. Ray deviation is not stabilized: deviation varies between far and near vision, wearers will experience swim effect. And this even gets worse when prescribed addition increases.
- For the first time with Varilux S series, local shape and power are managed element by element, leading to an exclusive geometry. Ray deviation is controlled element by element: deviation variations are dramatically reduced. Wearer will experience equilibrium in motion. And this remains true even for high prescribed addition.

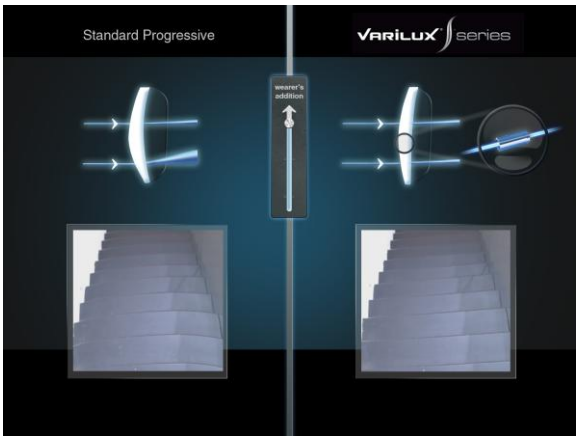


Figure 6 : Varilux S series versus a standard progressive lens

Benefits of Nanoptix

Nanoptix benefits have been demonstrated through both In-Lab R&D analysis and R&D experiments.

In-Lab R&D analysis show that Varilux S series benefits of up to 90% of swim effect reduction compared to main premium progressive lenses[2].

Nanoptix benefits have also been tested through an Essilor R&D virtual lens simulator experiment showing that Nanoptix technology is clearly chosen by a large majority of subjects compared to the classical technology [7].

S Digital Surfacing

As Nanoptix exclusive calculation process leads to extremely complex surfaces, Essilor whole manufacturing process has deeply evolved. S Digital Surfacing, a

new patented process, benefits from the full performances of Digital Surfacing and is up to 5 times more accurate thanks to an exclusive close loop process.

3- SynchronEyes™, the design revolution

Natural binocular vision

Humans have 2 eyes separated in space by a short distance (63 mm in average) so that an extensive region of the outside world is seen simultaneously with both eyes from slightly different point of views. Each retina transmits its monocular image, through the visual pathways, to the visual cortex which will analyze and transform them into a unique three-dimensional perception of the world. This process forming a clear and single perception of the surrounding world is called binocular vision.

Binocular vision is divided in three incremental stages [10]:
- Simultaneous perception is the first grade of binocular vision. Visual cortex receives and analyzes stimuli from both eyes without suppressing information coming from one eye.
- The second grade is the fusion process. It allows integration of the 2 retinal images projected onto the visual cortex in a single perception. Good fusion results in optimized binocular summation. Binocular summation is said to occur when visual detection or that discrimination with 2 eyes over-performs the performance of the best eye : for instance literature shows improved visual acuity and better contrast sensitivity with the two eyes compared to monocular vision.
- The third and last stage of binocular vision is stereopsis: although the images of the outside world projected on each retina are essentially two-dimensional, humans perceive the world in 3 dimensions. Stereopsis provides an acute depth and distance perception.

Impact of progressive lenses on natural binocular vision

Studies show that balanced (similarly shaped and sized) right and left retinal images are needed for good binocular summation and depth perception:
- Castro et al. (2009) [11] demonstrated that when both eyes have the same level of optical quality, the binocular summation is higher whatever the age. They measured the eye Strehl ratio for each eye, which is a good indicator of optical quality, and found a statistically significant correlation between binocular summation and difference of Strehl ratio between the 2 eyes.
- Castro et al. (2010) [12] conducted also a further experiment dealing with depth perception : "The aim was to evaluate the role of interocular differences in retinal-image quality in stereoscopic depth perception. Data were taken for 25 observers with ages ranging from 21 to 61 years. The results show a significant correlation between maximum disparity and interocular differences in the Strehl ratio: the lower interocular differences, the higher maximum disparity."

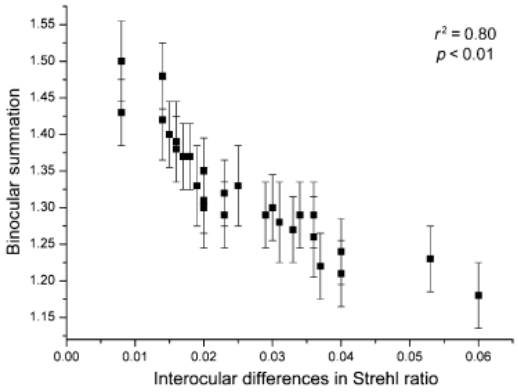


Figure 8: From Castro et al. 2009

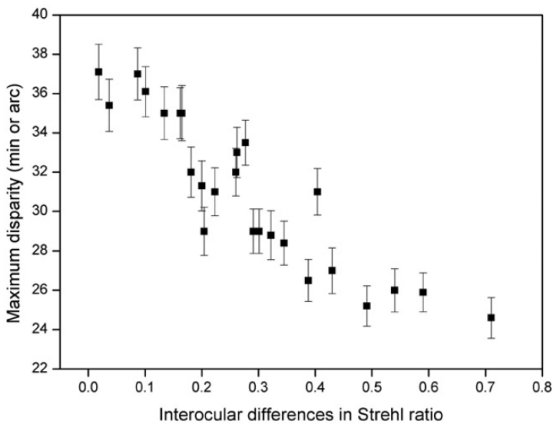


Figure 9: From Castro et al. 2010

But progressive lenses disturb the right and left natural retinal images balance, and thus affect natural binocular vision. This can lead to difficulties in image fusion, depth perception, and to reduced binocular fields of vision.

Current levers to manage binocular vision

The management of binocular vision in ophthalmic products has been claimed for many years. In terms of optical design, 2 levers are currently used to improve right and left retinal image balance:

- The first lever is the location of vision zones that have to be associated to the needs of convergence. The vision zones of the lens design have to be centered along a meridian line, which represents the main gaze directions used by a wearer to see through the lenses at all distances and passes through the far vision zone and the near vision zone. In particular, the near vision zone has to be laterally shifted compared to the distance vision zone, in order to take into account the prismatic effects and the eye convergence at near: it is the inset which can be calculated as a function of monocular pupillary distance, vertex distance, reading distance, prescription (far vision power, addition power).

- The second lever is the distribution of powers and aberrations all over the lens, which should be considered in the case of off centered vision. In order to preserve right and left retinal images balance, manufacturers have claimed for years good nasal/ temporal designs will fix this, even in case of astigmatic prescriptions.

However, today, whatever the method, lens calculation is based on « monocular » conception which takes into account a monocular referential centered on the considered Eye Rotation Center, the considered eye prescription, the considered eye optical performances... It ensures performances for each eye, but it doesn't guarantee the balance between right and left retinal images.

SynchronEyes, a design revolution

Based on the most advanced Human Research, SynchronEyes takes into account the physiological differences between the 2 eyes: the optical design for a given eye, takes into account the prescription of the other eye, to guarantee similar retinal images between the 2 eyes. The prescriptions of both eyes are thus required even to order a single lens.

To calculate lenses with SynchronEyes, Essilor designers use a binocular optical system based on 3 elements:
- The cyclopean eye: just like the Cyclops of Greek mythology, humans see the world as though from a single cyclopean eye situated between the two anatomical eyes. Cyclopean eye is placed at mid-distance from the 2 eyes rotation centers
- A 3D environment, which describes the distance of the objects seen as a function of the gaze direction.
- A cyclopean coordinate system described figure 10: for each gaze direction ($\alpha 1$,$\beta 1$) of the cyclopean eye, the 3D environment provides a given object point O. From object point O, ray tracing provides the right eye gaze direction ($\alpha R1$,$\beta R1$) as well as the left eye gaze direction ($\alpha L1$,$\beta L1$). Right and left gaze directions cross zones of respectively right and left lenses called "corresponding zones".

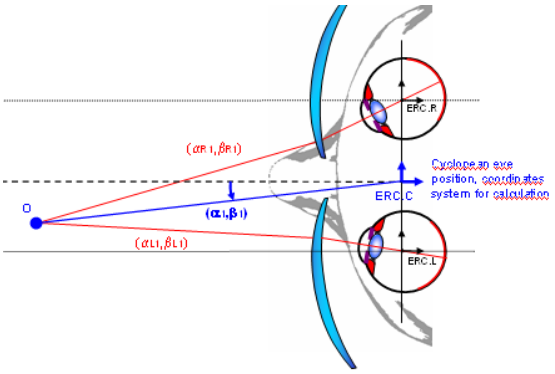


Figure 10: Cyclopean coordinate system

Contrary to monocularly designed lenses, SynchronEyes enables similar right and left "corresponding zones" and thus right and left similar retinal images through 3 steps :
- Step 1 : measurement of the wearer personnalized parameters to build his own binocular optical system
- Step 2 : definition of a binocular optical target, according to the wearer parameters and the binocular system
- Step 3 : applying binocular optical design to the both eyes thanks to the optimization of the right and left lenses according to the binocular optical target

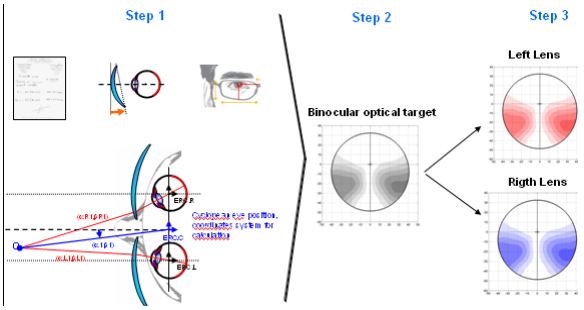


Figure 11: SynchronEyes Technology

SynchronEyes benefits

Let's compare Varilux S series benefiting of SynchronEyes with a standard lens (Figure 12):
- For a standard lens: Right and left lenses are calculated independently. When looking in periphery, wearer gaze crosses right and left lenses at zones having different optical performances. Right and left retinal images are of different quality resulting in binocular unbalance. Wearer perceives reduced fields of vision, even worse when the prescription difference between the 2 eyes increases.
- With Varilux S series, for the first time ever, right and left lenses calculation are synchronized by taking into account prescriptions differences between the 2 eyes. When looking in periphery, wearer gaze crosses right and left lenses at zones having similar optical performances. Right and left retinal images are of similar quality ensuring binocular balance. Wearer experience wide angle vision, even when the prescription differences between the 2 eyes increases.

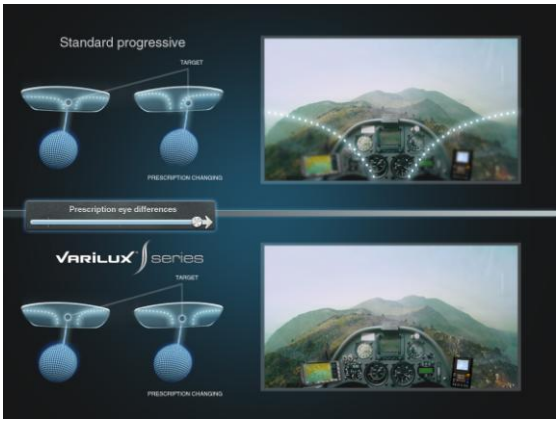


Figure 12:Varilux S series vs a standard progressive lens
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SynchronEyes benefits have been demonstrated through In-Lab R&D analysis: results show that Varilux S series are up to 50%[3] wider binocular fields of vision compared to premium progressive lenses.

4 - Varilux S Series, overall performances

Varilux S series, approved by wearers

Since 2004, Essilor has conducted systematic wearers tests on its leading brands Varilux®, Crizal® and Xperio® before putting them on the market, placing the wearer at the heart of products performance. As all previous Varilux generations, Varilux S series has been tested by real wearers around the world in real-life conditions, through independent external third party studies.

These wearers test highlighted Varilux S series excellence vs Varilux Physio 2.0 : Varilux S series was ranked Number 1 on every lens features[4]. In particular:
- Varilux S series is N°1 when surroundings move

- Varilux S series is N°1 for quality and fields of vision
- With outstanding wearer comments : « Less sensation of movement when I turn my head », « overall distortion not here anymore », « Less head movement to find focus », « Incredible clearness, everything remains clear until eyes can't turn anymore ».

A rigorous randomized, cross over design and double masked study

This wearers test has been conducted according to a rigorous randomized, cross over design and double masked study
- Randomized study : after a wash out period, wearers were randomly split in two half groups.
- Crossover design study : during a first trial period of approximately 2 weeks, one group wore Varilux S series, and the other group wore Varilux Physio 2.0. Then during the second trial period of approximately 2 weeks, then the two groups switched designs. Wearers evaluated designss after each period.
- Double masked study : neither the wearer nor the researcher knew what equipment was worn during trial periods and evaluations

The last study was a test that was conducted on a panel of 97 current progressive lens wearers following a full eye exam

Detailed results

These wearers tests lead to exceptional results in favor of Varilux S design (first step into Varilux S series range), which has been rated higher on every lens' features over Varilux Physio 2.0 : overall vision, distance vision, intermediate vision, near vision, dynamic vision (subject moving and surroundings moving), and adaptation. Overall vision and dynamic vision (subject moving) were even highly significantly better for varilux S design compared to Varilux Physio 2.0 (t-test: p-value<0.05).

95% of wearers[5] approved Varilux S design by rating overall vision positively. Most importantly, 8 out of 10 have highlighted the level of excellence of the product by giving to Varilux S Series outstanding comments to their overall vision[6]. And more than 1 wearer out of 2 confirmed a very fast adaptation with Varilux S design, only taking a few minutes.

With Varilux S design, wearers enjoy equilibrium in motion :
- when subject moves for **74%** of wearers[8]
- when surroundings moves for **78%** of wearers[7]

With Varilux S design, according to the wearers, they also experience wide angle vision at whatever distance[9].

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[1] : Fields of vision are based on binocular fields of vision analysis. Swim effect is based on beam deviation analysis. Dots represent mean values on all analyzed lenses. Varilux S design vs Varilux Physio 2.0 and 6 competition premium progressive products. Per product : 4 to 10 prescriptions analyzed from -3 Add2 to +2.5 Add2. In lab R&D testing, 2011.
[2] : Swim effect is based on beam deviation analysis. 90% represent the maximum gain extracted from all analyzed lenses. Varilux S design vs Varilux Physio 2.0 and 6 competition premium progressive products. Per product : 4 prescriptions analyzed from -3 Add2 to +2.5 Add2. In lab R&D testing, 2011.
[3] : Field of vision based on binocular field of vision analysis. 50% represent the maximum gain extracted from all analyzed lenses. Varilux S design vs Varilux Physio 2.0 and 6 competition premium progressive products. Per product : 10 prescriptions analyzed from -3 Add2 to +2.5 Add2. In lab R&D testing, 2011.
[4] : Based on average evaluation – Comparative wearer test (Varilux S design vs Varilux Physio 2.0) conducted by independant 3rd parties – 97 wearers – worlwide 2011
[5] : % of wearers who rated their overall vision with Varilux S design positively (10 or more out of 20)
[6] : % of wearers who rated their overall vision with Varilux S design very positively (15 or more out of 20)
[7] : % of wearers who rated Varilux S design very positively (15 or more out of 20) – Base : n=96/97 wearers
[8] : % of wearers who rated Varilux S design very positively (15 or more out of 20) – Base : n=97 wearers
[9] : Average evaluation of quality and width of vision from assessment on a 20 point scale – Base: n=96/97 wearers
* : Prof. José Sahel receives no compensation in a private capacity for the validation of these protocols