Progressive addition lenses—matching the specific lens to patient needs

James E. Sheedy, O.D., Ph.D.

The Ohio State University, College of Optometry, Columbus, Ohio

Background: The objective of this study was to use state-of-the-art methods to measure the optical characteristics of commonly available progressive addition lenses (PALs) and to develop derivatives of the optical measurements that can be used as guidelines in selection of lenses based on patients' visual needs.

Methods: The optics of 28 PALs currently on the market were measured with a Rotlex Class Plus lens analyzer. PALs were specified with plano distance power and a near add of +2.00 D. Data were normalized to plano at the location specified by each manufacturer and acquired from each data file in 1-mm vertical steps with respect to the fitting cross.

Results: The variance across lenses was greater than 2:1 for most measurements. Ratings were calculated based on equal weighting of zone width and area for distance, intermediate, and near zones, and also for magnitude of unwanted astigmatism.

Conclusions: The results demonstrate wide ranges of optical characteristics across the PALs tested in this study. Ratings of the distance, intermediate, and near zones, as well as rating of unwanted astigmatism can be used in selection of appropriate lenses to match patient visual needs.

Key Words: Bifocal, multifocal, ophthalmic optics, optics, presbyopia, progressive addition lenses

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Since introduction to the U.S. market in the 1960's,[1] progressive addition lenses (PALs) have steadily increased in share of the multifocal market. Studies have shown that a large percentage of patients prefer PALs, as compared to bifocal alternatives.[2-4] PALs supply a continuous change of power from distance through intermediate to near that provides the wearer with a seamless visual space and eliminates the unusable area of visual space surrounding the top line of a bifocal segment. The seamless lens is also cosmetically more pleasing than a bifocal lens. A detracting feature of PALs is that the design necessarily results in unwanted astigmatism in the periphery of the lens—usually located in the lower diagonals relative to lens center.[1]

There are an infinite number of possible PAL designs because they are designed with surfaces (usually the front surface) across which the curvatures change. Some designs result in wider and larger distance, intermediate, or near viewing areas.[5,6] The magnitude of unwanted astigmatism also depends on design. More recently, PALs with a short corridor or higher near zone have been developed to accommodate the shorter fitting heights required by small frame sizes. There is considerable interdependence of the sizes and locations of the viewing zones and the magnitude of unwanted astigmatism that make it currently impossible to design a lens that is optimized for all optical attributes.

There are also differences in the occupational and/or recreational visual needs of presbyopic patients. Some patients, such as professional drivers or many outdoor employees, have a greater demand for distance vision than near. Many indoor workers have a much greater demand for near and intermediate vision than distance. Lenses

Table 1. Progressive addition lenses measured in this study and key data; fitting cross and distance power locations are given in millimeters above the line that connects the lens markings

Progressive Addition Lens	Fitting cross wrt markings	Distance power wrt markings	Minimum Recommended fitting height
AO b'Active	2	5.5	18
AO Compact	2	5.5	17
AO Pro 15	2	5	22
Essilor Adaptar	4	8	18
Essilor Natural	4	8	18
Essilor Super No-line	4	8	20
Hoya Summit CD	4	8	14
HoyaLux ECP	4	6	18
HoyaLux GP Wide	4	8	18
J&J Definity	4	9	18
Pentax AF 150	0	5	21
Pentax AF Mini	0	5	17
Rodenstock Life AT	4	8	18
Rodenstock Life XS	4	8	16
Shamir Genesis	4	10	20
Shamir Piccolo	4	10	16
Signet Armorlite Kodak	2	8	18
Signet Armorlite Kodak Precise	4	7.5	20
Signet Armorlite Navigator Precision	2	8.5	19
SOLA Percepta	2	8	22
SOLA VIP	2	8	22
SOLA XL	2	8	22
SOLAMax	4	10	18
Varilux Comfort	4	8	18
Varilux Panamic	4	8	18
Vision Ease Outlook	4	9	18
Younger Image	2	8	18
Zeiss Gradal Top	6	9	18

wrt, With respect to.

Figure 1 The Rotlex Class Plus lens analyzer used in this study, with lens located on measurement stage.

with wider and larger distance, intermediate, or near optical areas would probably better meet the needs of wearers with visual needs at those viewing distances. Clinically, it would be useful to match the patient needs with a PAL design optimized to meet those needs. However, a systematic measurement and reporting of the distance, intermediate, near, and astigmatism characteristics of PALs has not been performed previously. The most-recent systematic report of PAL characteristics was in 1987.[1] The available PALs in the marketplace have almost completely turned over since then; that report included only contour plots of the lenses, which did not include quantification or analysis of the viewing zones.

The objective of this study is to use state-of-the art methods to measure the optical characteristics of commonly available PALs and to develop derivatives of the optical measurements that can be used as guidelines in selection of lenses, based on patients' visual needs.

Methods

Twenty-eight PALs, listed in Table 1, were selected for inclusion in this study. Lenses were selected in an attempt to include the most-common currently available lenses. However, because of the large number of designs available in the marketplace, the list of lenses included in this study is not exhaustive. All lenses were obtained from two optical laboratories (Advance Optical, Cleveland, Ohio and Interstate Optical, Berea, Ohio), except for the Johnson & Johnson Definity lens, which is not available through optical laboratories and was obtained from the manufacturer. Lenses were ordered to the following specifications: plano distance power, right lens, +2.00 add, manufacturer markings to be left on the lens.

All lenses were measured with a Rotlex Class Plus lens analyzer (*see* Figure 1). This instrument determines lens contour plots with a single measurement. The instrument is essentially a moire deflectometer, which uses a point source rather than a collimated beam. Diverging light from a laser point source is incident directly on the tested lens. The rays refracted by the lens under measure pass through two gratings and form a moire pattern on a diffusive screen. Proprietary image-processing algorithms convert the fringe data to arrays of local wavefront properties—in particular, the two principal curvatures and axis directions. These arrays are used to calculate two-dimensional maps of local power, cylinder, and axis of progressive lenses, and other phase objects with variable powers.

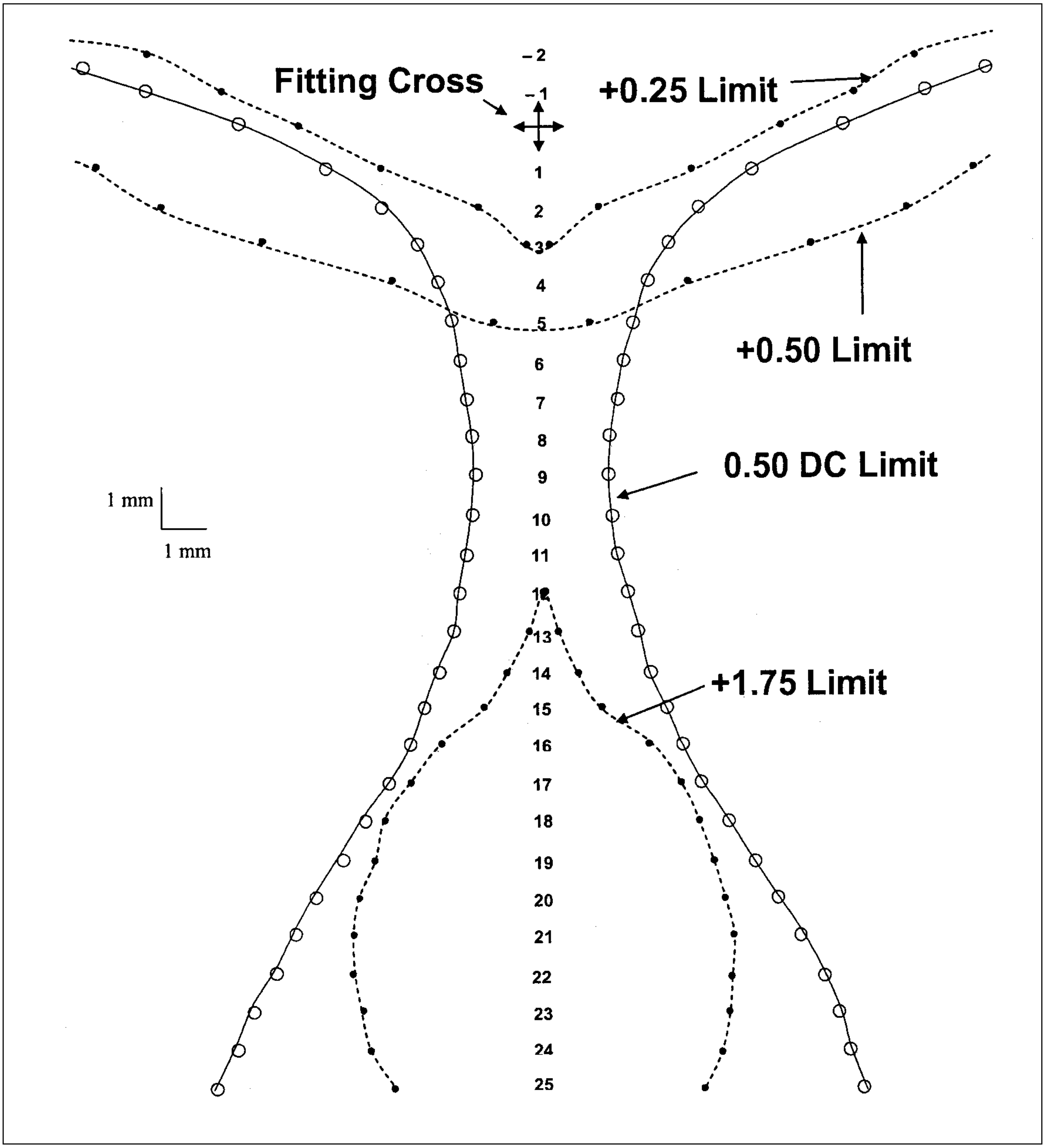

Figure 2 Schematic diagram of selected measurements taken from the measurement data file. Measurements were taken at 1-mm vertical steps (**Y** value). Diagram shows typical limiting values of +0.25, +0.50, +1.75, and 0.50 DC.

All lenses were measured with the prism reference line markings (the lens markings that are 34 mm apart and represent the 0–180 line on the lens) appropriately aligned in the instrument, and the data file was saved after measurement. For analysis, the locations of the fitting cross, distance power, and near power—as specified by the manufacturer (*see* Table 1) with respect to the 0–180 line—were identified in the data file. Although all lenses were ordered to have plano distance power, power errors within manufacturing tolerance existed. All measurements taken from the data file were determined with the "DST" mode of the instrument—i.e., all the measures on each lens were normalized to an assigned power of plano at the manufacturer-specified distance location.

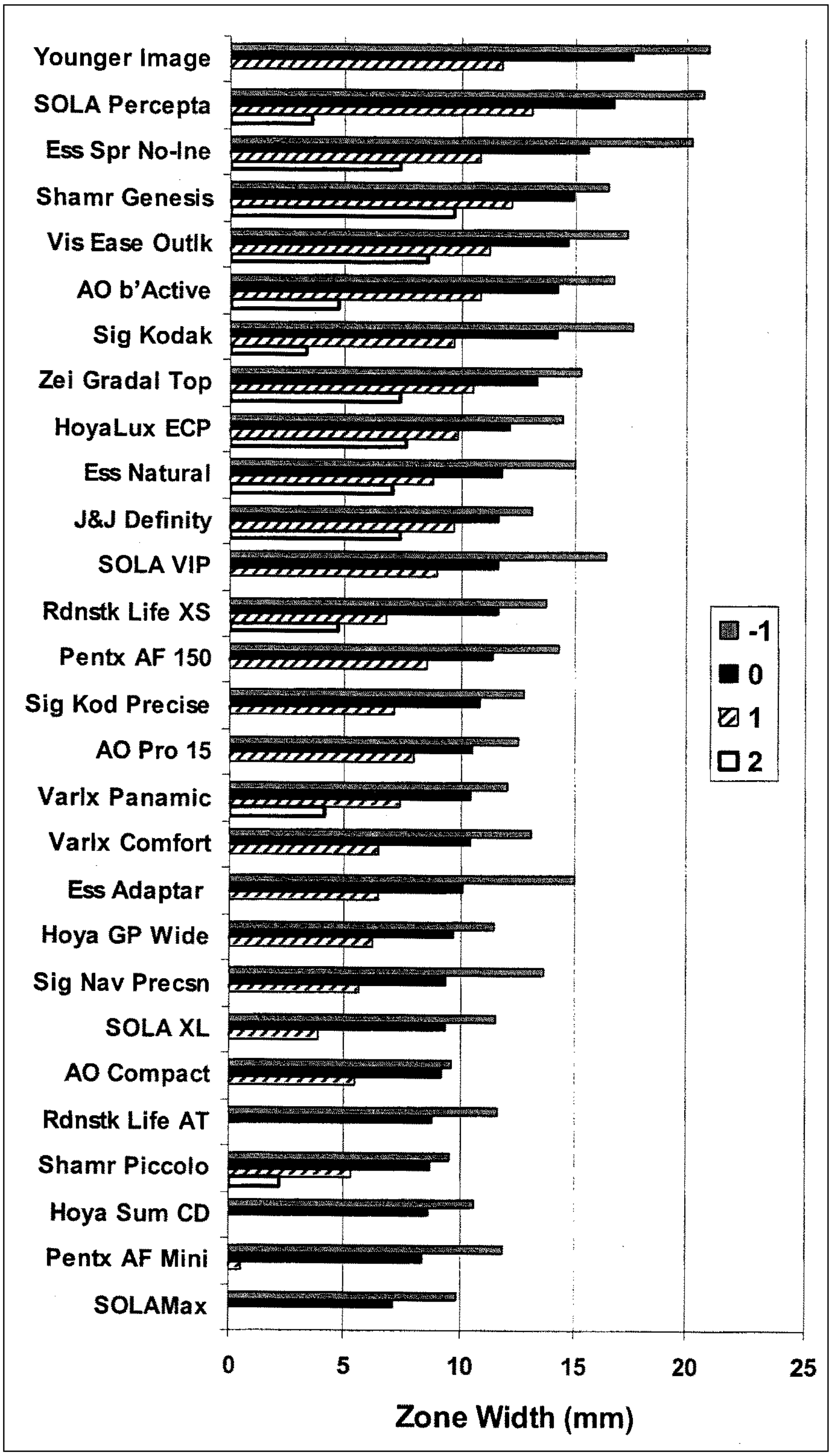

Figure 3 Width of the distance power (within ± 0.25 DS and less than 0.50 DC) at fitting cross (0), above (–1 mm), and below (1 and 2 mm) the fitting cross. Not all lenses had distance area at 1 and 2 mm below fitting cross. Lenses sorted by width at fitting cross.

Data were acquired from each file in a step-wise manner by examination of the data files in 1-mm vertical increments, beginning at 10 mm above the fitting cross and extending to 25 mm below the fitting cross. Although the Rotlex instrument specifies vertical location with respect to the 0–180 line, for the purposes of this study, all vertical locations were converted so that the manufacturer-specified location of the fitting cross was the reference point. In this manner, measurements across lenses are referenced to the location that is intended by the manufacturer to be placed before the pupil of the eye; thus, the visual effects of the lenses can be compared to one another with a common visual reference point. Vertical location (Y coordinate) is specified as negative for locations above the fitting cross and positive for below. At each Y value from –10 to +25, the following data points were recorded, moving outward from the center of the corridor: the left and right X coordinates of the limits of 0.50 cylinder, +0.25 sphere (distance area only), +0.50 sphere (distance area only), +1.75 (near area only), and +2.00 (near area only); value of the greatest amount of unwanted cylinder; and spherical power (maximum plus power) in the center of the corridor. An illustration of some of these measurements is provided in Figure 2. Separately, the data files were analyzed to provide the following additional data for each 0.25 D increment of power along the center of the corridor: Y location, left and right X values of 0.50 cylinder limits, and maximum unwanted cylinder at that level.

This eliminated the effects of laboratory surfacing variances at the distance center and normalized all lenses to plano power at the manufacturer-specified distance location of each lens.

In data analysis, unwanted cylinder of 0.50 DC was used as a limit of zone width. This value represents a spherical equivalent of 0.25 D, and more assuredly creates blur than a limit of 0.25 DC.

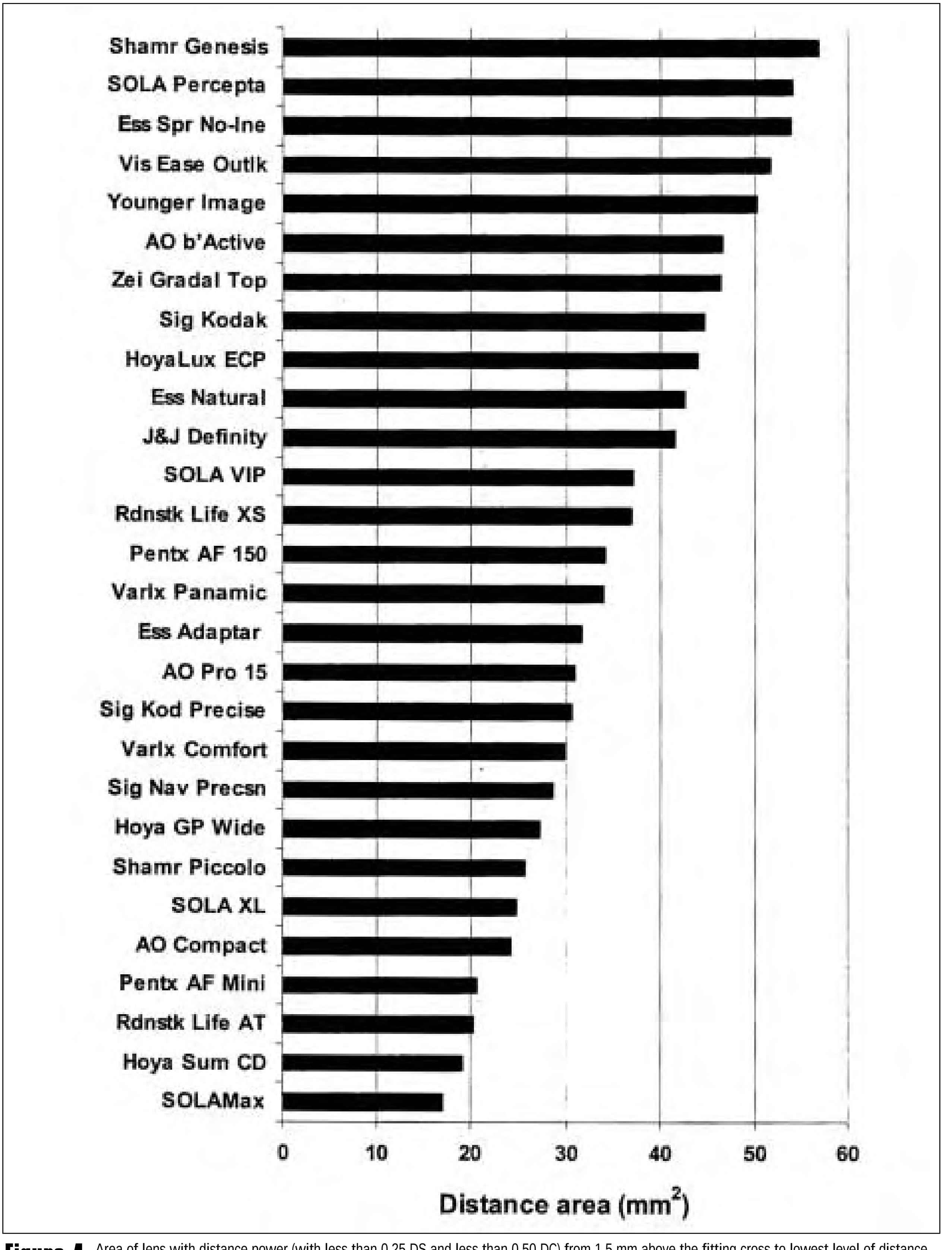

Figure 4 Area of lens with distance power (with less than 0.25 DS and less than 0.50 DC) from 1.5 mm above the fitting cross to lowest level of distance power.

Results

Distance power zone

The width of the distance zone at the level of the fitting cross (located at the pupil of the eye) is particularly meaningful to vision because it represents the width of clear distance vision with the eyes in the straight-ahead position—i.e., the horizon. For purposes of this study, unwanted refractive error of 0.25 DS or 0.50 DC—whichever is most limiting—constitutes the edge of the distance viewing zone. Although 0.25 D is greater than the power tolerance for lower powered lenses (±0.13 D) as specified in the ANSI Z80.1 standard,[7] it has been chosen as the limit, because refractions and prescriptions are typically in 0.25 D steps and patients are generally sensitive to +0.25 D blur at distance. Zone widths were not necessarily symmetrical about the fitting cross, and the zone width measures derived from the data do not retain information about asymmetry.

The distance zone widths of the tested lenses defined to the first +0.25 DS or 0.50 DC power—whichever was most restrictive on each side—are displayed in Figure 3. Zone widths at the level of the fitting cross, 1 mm above and 1 and 2 mm below the fitting cross, are shown. Lenses are sorted by zone width at the level of the fitting cross and presented in decreasing order, so that the widest zones are at the top. All lenses had a distance zone level with the fitting cross, three lenses did not have a distance area 1 mm below the fitting cross, and 15 of the 28 lenses did not have a distance area 2 mm below the fitting cross. Only two lenses had a distance area 3 mm below the fitting cross, and none extended to 4 mm below the fitting cross.

Because of the normal downward gaze position of the eyes, the distance zone near the fitting cross is the most important for visual use. All of the PALs had limitations on distance zone width at the level of the fitting cross and also 1 mm above the fitting cross. For this study, the distance area of the lens was calculated by summing the zone widths, from 1 mm above the fitting cross down to the lowest level of the distance zone, for each lens. This effectively integrates the area in steps of 1 mm. The width at each 1-mm step, therefore, represents the area extending 0.5 mm above and below it. Thus, the area calculation above represents the area of the lens from 1.5 mm above the fitting cross to the lowest area with the distance power. Because 1 mm on the lens surface represents 2 degrees of eye movement (assuming 14-mm vertex distance and 15 mm from the corneal apex to the center of ocular rotation), the upper extent of the calculated area represents 3 degrees of visual gaze angle above the fitting cross, or 3 degrees above the horizon for an upright head posture. Data for the calculated distance zone area are presented in Figure 4, with the lenses sorted according to decreasing zone area.

Intermediate power zone

The widths of the intermediate zone for add powers of +0.75, +1.00, +1.25, and +1.50 are shown in Figure 5. The intermediate range of powers (+0.75 to +1.50 D) includes the 50% power (+1.00 D) and is slightly biased to higher intermediate adds (inclusion of +1.50) because an extremely common intermediate task is viewing a computer display that is typically at a distance that requires 50% to 75% of the near add.[8] Data are sorted on the basis of zone width at +1.25 for the same reason.

The areas of the lenses with clear intermediate powers were calculated by summing the area from +0.75 to +1.50 D add in three increments (0.75 to 1.00 D, 1.00 to 1.25 D, 1.25 to 1.50 D), as limited laterally by 0.50 DC. The area in each increment was calculated by determination of the zone width at the upper and lower end of the zone increment (e.g., the width at +0.75 D and +1.00 D for the 0.75 to 1.00 increment), averaging the two widths, and then multiplying the average zone width by the Y difference of the locations of the upper and lower powers. Intermediate zone data are presented in Figure 6.

Near power zone

The level of first appearance (descending from the fitting cross) of +1.75 and +2.00 adds are displayed in Figure 7. Although all lenses had a nominal near add power of +2.00 D, 12 of the 28 designs did not progress entirely to +2.00 D, similar to the finding in a previous study.[1] However, it should be noted that add data were collated in 0.25 D steps, and many of the lenses that did not reach a +2.00 add came close nonetheless. The maximum add power attained across the lens population was +1.996 D

±0.109 (mean ± standard deviation). All further analyses of the near power zone are based on zones with +1.75 D add or greater. Lenses in Figure 7 are sorted by the lowest Y value of the first +1.75 D add, resulting in the lenses with higher appearance of the +1.75 add sorted to the top. Lenses with a higher appearance of the +1.75 add are better suited for the shorter fitting heights usually associated with smaller frames. The near zone widths (constrained by both an add power of +1.75 or greater and 0.50 DC limits) at 14, 16, 18, and 20 mm below the fitting cross are displayed in Figure 8. Lenses are sorted in decreasing order of the zone width at 18 mm in order that wider zones are at the top. Many lenses do not have a near zone at 14 mm below the fitting cross; some do not at 16. It should also be noted that, although the lenses are sorted by near zone width at 18 mm, zone width ordering for other levels below fitting cross would be quite different. This is because the rate at which zone width increases is design dependent.

The area of the near zone was calculated in 1-mm intervals similar to the distance calculation; the zone limits were constrained by both an add amount of +1.75 DS or greater and 0.50 DC width limits. The cumulative areas of the near zone down to 16.5, 18.5, and 20.5 mm below the fitting cross are shown in Figure 9.

Unwanted astigmatism

The highest magnitude of unwanted astigmatism for each lens is displayed in Figure 10.

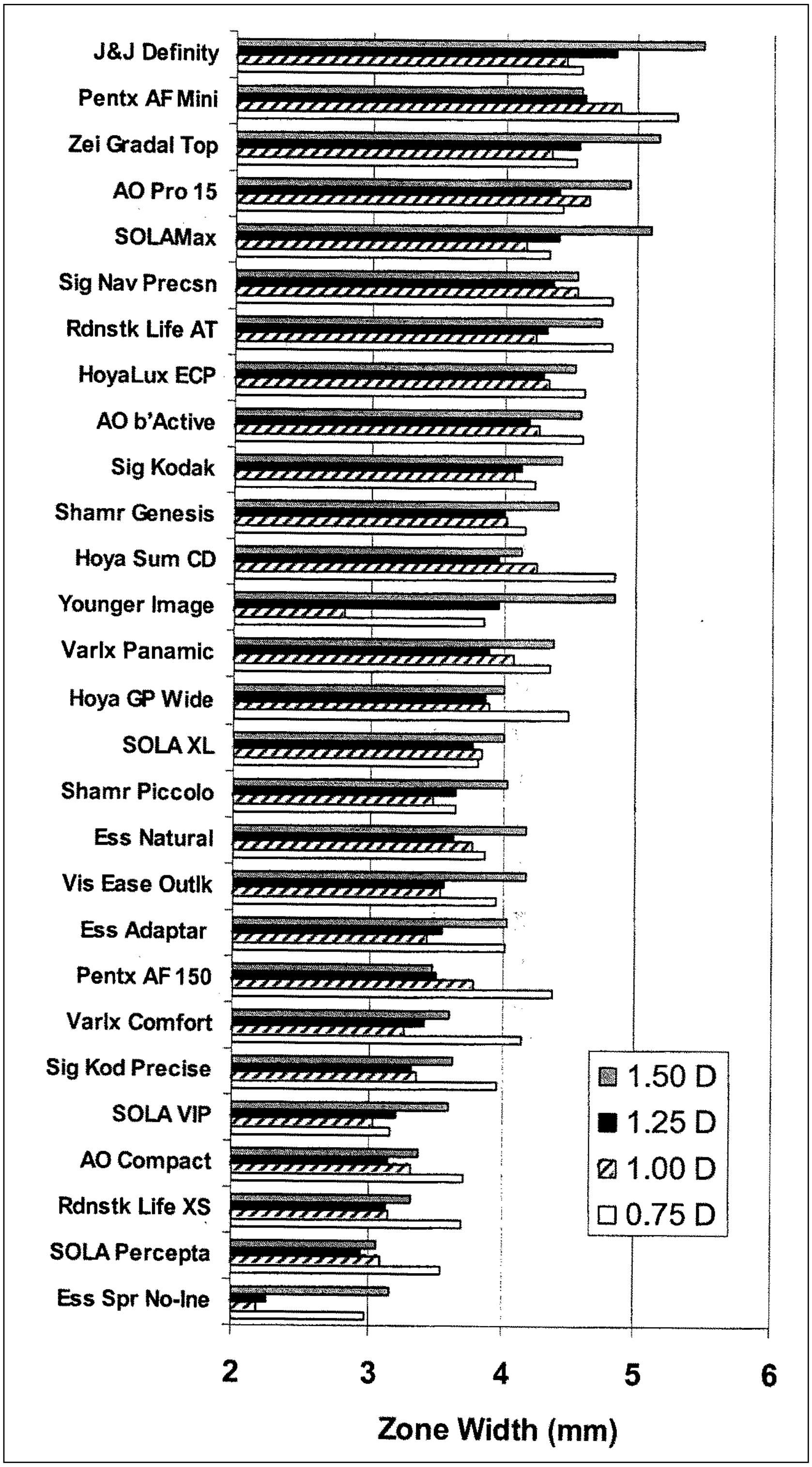

Figure 5 Width of the intermediate zone (0.50 DC limits) at add powers of +0.75, +1.00, +1.25, and +1.50 D, lenses sorted by width at +1.25 D.

Discussion

The results demonstrate wide ranges of optical characteristics across the PALs tested in this study. For most of the parameters shown in Figures 3 through 10, the variance is greater than 2:1; for some it is greater than 3:1. Some lenses provide

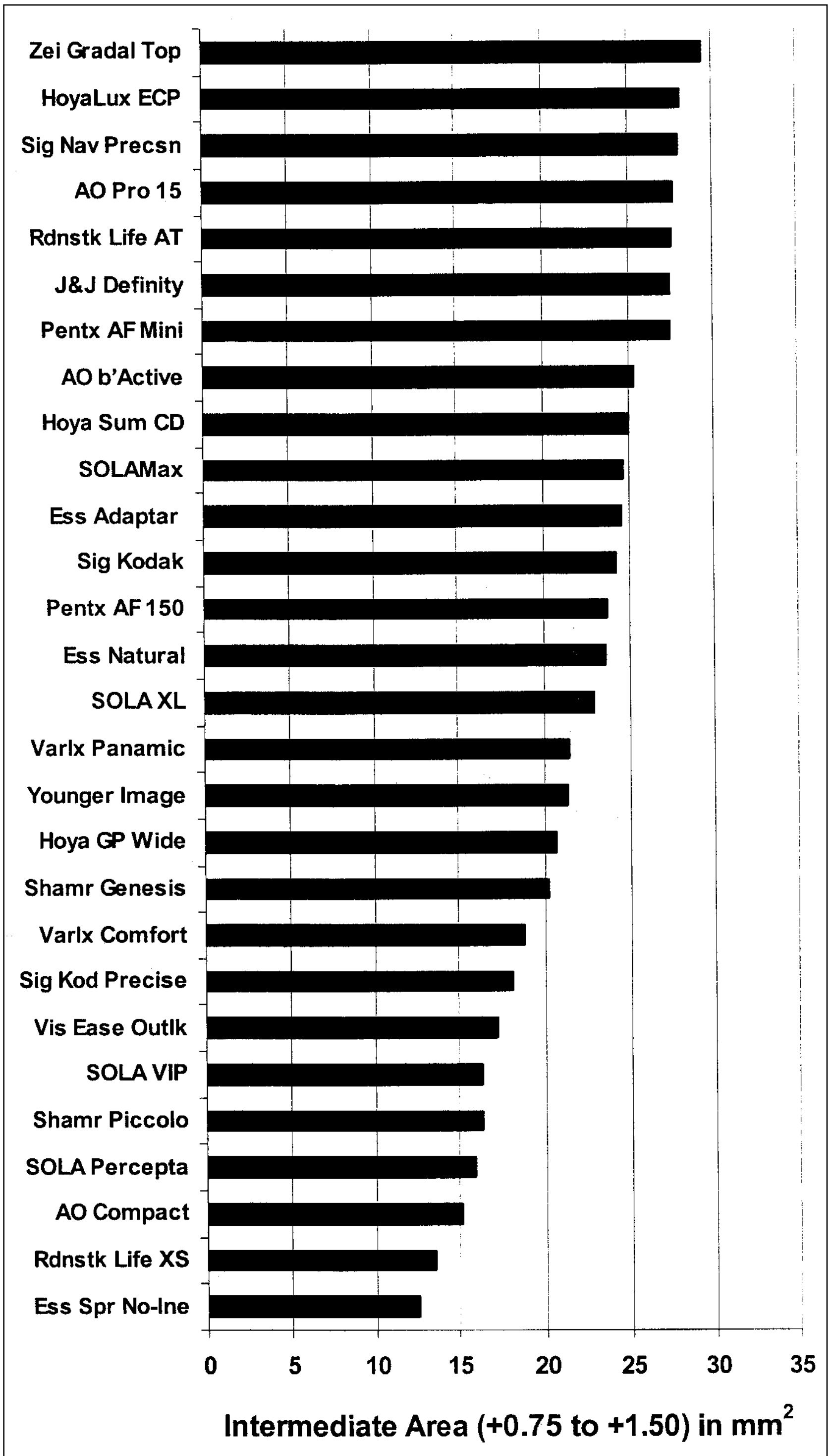

Figure 6 Area of intermediate power (+0.75 to +1.50 add and less than 0.50 DC) in mm^2.

what appear to be better distance, intermediate, or near characteristics than others. The intent of this study is to provide this optical information about PALs in a form that can be clinically useful in matching lens characteristics to patient visual needs. The PAL parameters reported in Figures 3 through 10 were selected because they have *prima facie* relevance to vision. However, this assumption warrants further investigation. If these parameters are to be used to evaluate lens performance, then the range of values for each parameter should be reasonably related to visual performance. For example, if the range of values for a particular parameter exceeds values that are meaningful for vision, then the parameter may not be a valid discriminator.

All the following angle analyses assume a vertex distance of 14 mm. A 14-mm vertex distance results in 1 mm on the lens surface equating to 2 degrees of visual space. The visual angles of clear vision through a PAL can be increased with a shorter vertex distance. An 11-mm vertex distance results in 1 mm equating to 2.2 degrees, whereas a 16-mm vertex distance results in 1 mm equating to 1.85 degrees.

Distance zone

The utility of distance zone width depends on the extent to which the eye rotates to use peripheral portions of the lens. Uemera et al.[9] studied eye and head movement in response to the appearance of lateral fixation stimuli. This task is similar to viewing a peripheral object while driving. Eye movement occurs before head movement; therefore, there is a large initial eye movement followed by a head movement accompanied by an eye movement in the return direction. For lateral stimuli at 10 and 20 degrees, initial target acquisition was entirely with eye movement. However, the final resting eye rotations were 2 and 5 degrees, respectively. For lateral stimuli of 30, 40, and 50 degrees, initial eye rotations were 28, 33, and 41 degrees, respectively; final eye rotations were 11, 15, and 19 degrees, respectively. In summary, the final resting position of the eyes can be up to 19 degrees to one side (38 degrees total, considering both lateral directions) and the initial eye movement can be up to 40 degrees to one side (80 degrees total). Because 1 mm on the lens surface equates to 2 degrees of eye rotation, the final and initial eye movements require distance zone widths of 19 and 40 mm, respectively. The data in Figure 3 show that no lenses meet the 19-mm width requirement at the level of the fitting cross (straight-ahead gaze position), and only four lenses meet or exceed it at 1 mm above the fitting cross (2 degrees superior gaze angle). None of the lenses come close to meeting the 40-mm width requirement. This leads to the conclusion that even the upper end of the distance zone widths in Figure 3 limits normal visual function for lateral gaze changes on the horizon (or 3 degrees above it) for wearers with their heads in a normal upright posture—thus, larger values within the range should improve ability to clearly see peripherally fixated objects.

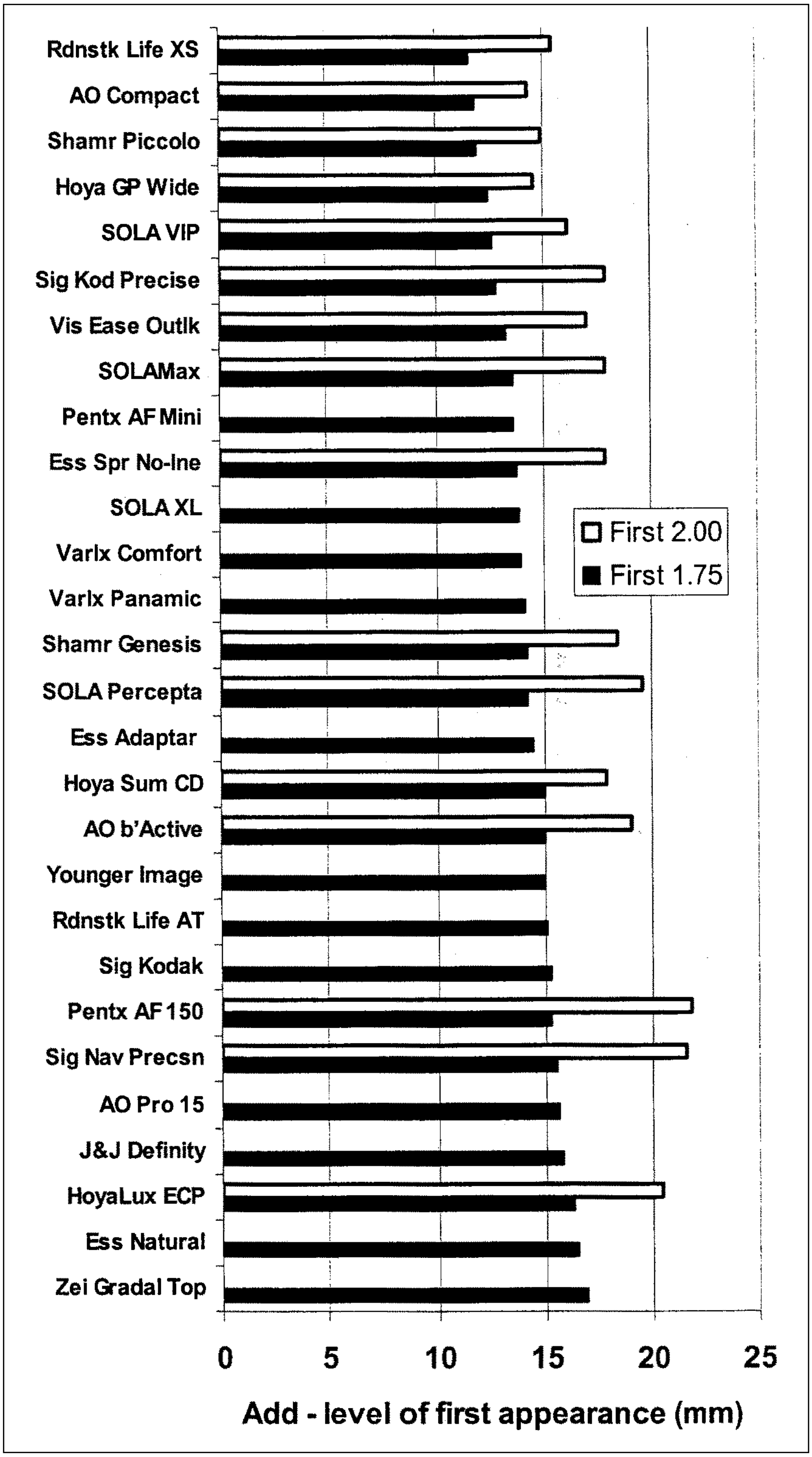

Figure 7 First distance along corridor (descending from fitting cross) at which +1.75 and +2.00 additions occur—sorted by +1.75 data. Not all lenses achieved +2.00 add.

The zone width level with the pupil seems particularly related to distance visual performance, because it represents vision on the horizon with normal head position. However, the total area of the distance zone close to and below the fitting cross (we typically gaze downward) as displayed in Figure 4 also seems important. The lens orderings in Figures 3 and 4 are similar, but contain some differences. In order to represent distance visual performance, a metric comprised of equal parts of both parameters was developed. Area is calculated as height times width (integrated). Therefore, a metric with equal representation of area and width effectively is

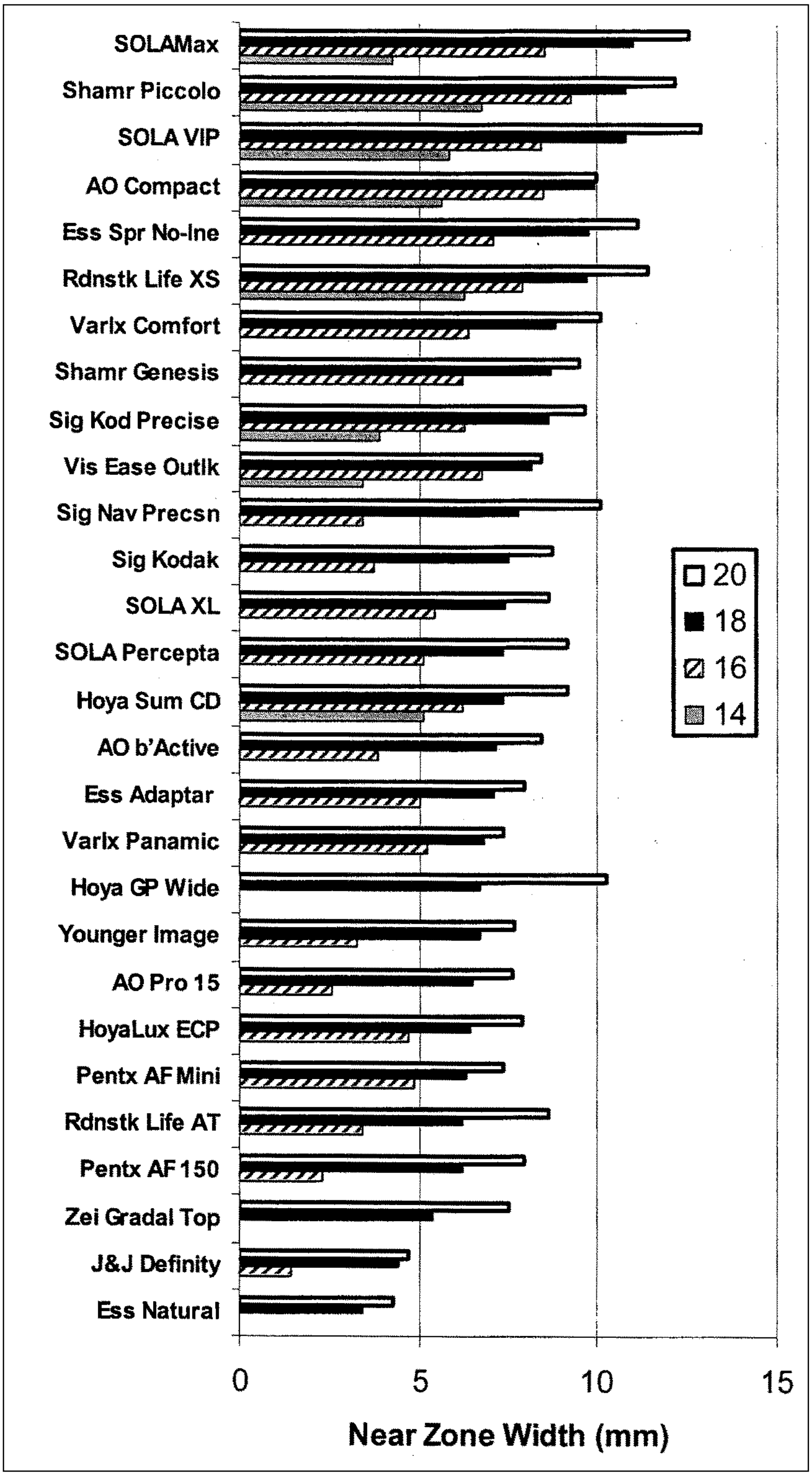

Figure 8 Width of the near area (+1.75 D add or greater and less than 0.50 DC) at 14, 16, 18, and 20 mm below the fitting cross—sorted by width at 18 mm. Not all lenses had near zone widths at all distances below fitting cross.

weighted twice as much for horizontal dimension as for vertical dimension. Greater weighting of the horizontal than vertical component seems appropriate, given the greater use of horizontal than vertical eye movements in the performance of most critical tasks, such as driving, spectator events, computer viewing, and reading. For each lens, a scalar value from 0 to 100 was determined for zone width at the fitting cross (based on the proportional location between 5 at the low end and 20 at the high end) and also for total distance area, as shown in Figure 4 (based on proportional location between 15 and 60 mm^2). The upper and lower limits of the ranges were selected to closely encompass the range of values—a strategy continued in further analyses (discussed later). The two scalar values were averaged to develop a final rating value for utility of the distance zone—the resulting ratings are shown in Table 2.

Intermediate zone and astigmatism

The width and area of the intermediate zone are presented in Figures 5 and 6. The validity of these measures, or their relatedness to how we use our eyes, can be investigated by analyzing the visual needs of viewing a computer display. A 19-inch computer display, tilted 10 degrees away at the top and at a viewing distance of 60 cm, subtends a horizontal angle of 35.7 degrees and a vertical angle of 26.8 degrees. The entire display subtends a solid visual angle of 956.8 degrees^2. A quarter of the screen therefore subtends 239.2 degrees^2. These convert to a need for 17.85-mm zone width to fixate both edges of the display and 59.8 mm^2 of lens surface to fixate 25% of the screen. The values in Figures 5 and 6 do not approach these requirements; thus, larger numbers within the

Table 2. Calculated ratings* for distance, intermediate, and unwanted astigmatism

Specialty usage—calculated ratings					
Distance	**Rating**	**Intermediate**	**Rating**	**Astigmatism**	**Rating**
SOLA Percepta	88.1	Zei Gradal Top	91.3	J&J Definity	93.3
Younger Image	87.4	J&J Definity	91.1	Varlx Panamic	70.0
Shamr Genesis	83.6	Pentx AF Mini	87.2	AO Pro 15	69.3
Ess Spr No-lne	83.2	Sig Nav Precsn	84.6	AO Compact	66.7
Vis Ease Outlk	77.2	AO Pro 15	84.6	Rdnstk Life AT	66.0
AO b'Active	69.3	HoyaLux ECP	83.6	Pentx AF Mini	61.3
Sig Kodak	67.1	Rdnstk Life AT	82.7	Pentx AF 150	61.3
Zei Gradal Top	65.4	SOLAMax	76.7	AO b'Active	60.7
Ess Natural	54.6	AO b'Active	74.8	Sig Kod Precise	60.7
J&J Definity	53.0	Sig Kodak	71.0	SOLAMax	59.3
SOLA VIP	47.9	Hoya Sum CD	70.0	Shamr Genesis	55.3
Rdnstk Life XS	47.8	Ess Adaptar	62.0	Younger Image	54.0
HoyaLux ECP	47.4	SOLA XL	61.7	Shamr Piccolo	54.0
Pentx AF 150	43.5	Younger Image	61.0	Ess Adaptar	48.0
Varlx Panamic	39.3	Ess Natural	60.8	Hoya Sum CD	47.3
Sig Kod Precise	37.3	Varlx Panamic	60.2	Rdnstk Life XS	46.7
AO Pro 15	36.4	Pentx AF 150	59.1	Sig Kodak	43.3
Ess Adaptar	35.3	Shamr Genesis	58.9	Vis Ease Outlk	42.0
Varlx Comfort	34.7	Hoya GP Wide	57.8	Varlx Comfort	39.3
Hoya Sum CD	30.1	Varlx Comfort	45.4	Ess Natural	38.7
Sig Nav Precsn	29.1	Vis Ease Outlk	44.0	Hoya GP Wide	38.0
SOLA XL	24.9	Shamr Piccolo	43.2	Zei Gradal Top	37.3
Hoya GP Wide	24.5	Sig Kod Precise	42.3	HoyaLux ECP	35.3
AO Compact	23.6	SOLA VIP	35.9	SOLA XL	31.3
Shamr Piccolo	23.1	AO Compact	31.9	Sig Nav Precsn	30.0
Rdnstk Life AT	17.6	SOLA Percepta	30.7	SOLA Percepta	30.0
Pentx AF Mini	16.2	Rdnstk Life XS	27.6	SOLA VIP	8.0
SOLAMax	7.1	Ess Spr No-lne	10.8	Ess Spr No-lne	-29.3

* Higher ratings indicate larger and wider areas of vision and lower astigmatism magnitude.

measured ranges represent greater abilities to fixate the task without head movement.

Similar to the approach for distance vision, a scalar value—equally weighted for zone width and zone area—was determined. A scalar value from 0 to 100 was determined based on zone width for +1.25 D (based on proportional value between 2 and 5 mm) and on zone area (as represented in Figure 6) based on location between 10 and 30 mm^2. The two scalar values were averaged to develop a rating value that represents utility of the intermediate zone—the resultant ratings are shown in Table 2.

Likewise, scalar values of 0 to 100 were determined for the unwanted astigmatism based on the magnitude within the range of 1.25 D to 2.75 D—with higher ratings assigned to lower amounts of astigmatism. Those ratings are also provided in Table 2.

Near zone

The width and area of the near zone are presented in Figures 8 and 9. The validity of these measures can be investigated by analyzing the visual needs of reading. A standard 8.5" × 11" piece of paper tilted 20 degrees away at the top

Table 3. Calculated ratings for near zone

Near specialty usage—calculated ratings

Fit Height 16	Rating	Fit Height 18	Rating	Fit Height 22	Rating	Fit Height 26	Rating
Shamr Piccolo	28.0	Shamr Piccolo	45.1	Shamr Piccolo	76.8	SOLA VIP	111.3
Rdnstk Life XS	27.2	AO Compact	41.1	SOLA VIP	76.2	SOLAMax	106.9
AO Compact	24.0	Rdnstk Life XS	40.2	SOLAMax	74.0	Shamr Piccolo	103.8
SOLA VIP	22.5	SOLA VIP	38.8	Rdnstk Life XS	71.9	Rdnstk Life XS	102.9
Hoya Sum CD	17.1	SOLAMax	38.3	AO Compact	65.9	Hoya GP Wide	98.3
SOLAMax	16.3	Vis Ease Outlk	30.4	Ess Spr No-lne	63.3	Ess Spr No-lne	80.1
Sig Kod Precise	14.8	Ess Spr No-lne	29.8	Hoya GP Wide	59.2	Hoya Sum CD	80.1
Vis Ease Outlk	13.0	Sig Kod Precise	28.6	Sig Kod Precise	57.3	Varlx Comfort	80.1
Hoya GP Wide	3.4	Varlx Comfort	26.6	Varlx Comfort	56.9	HoyaLux ECP	78.1
J&J Definity	0.0	Shamr Genesis	25.7	Shamr Genesis	54.2	Sig Nav Precsn	77.2
Varlx Panamic	0.0	Hoya Sum CD	23.2	Sig Nav Precsn	52.0	Sig Kod Precise	74.4
AO Pro 15	0.0	SOLA XL	22.8	Vis Ease Outlk	52.0	AO Compact	71.9
Rdnstk Life AT	0.0	Varlx Panamic	21.6	SOLA Percepta	50.1	SOLA Percepta	67.0
Pentx AF Mini	0.0	SOLA Percepta	20.8	SOLA XL	48.7	Shamr Genesis	63.2
Pentx AF 150	0.0	Pentx AF Mini	20.2	Hoya Sum CD	46.6	Pentx AF 150	62.9
AO b'Active	0.0	Ess Adaptar	19.7	Sig Kodak	46.3	Sig Kodak	61.4
Shamr Genesis	0.0	HoyaLux ECP	15.5	AO b'Active	44.8	SOLA XL	61.3
Younger Image	0.0	AO b'Active	14.6	Ess Adaptar	43.9	Ess Adaptar	60.6
Ess Adaptar	0.0	Sig Kodak	14.1	Rdnstk Life AT	43.6	Vis Ease Outlk	59.5
Sig Kodak	0.0	Rdnstk Life AT	13.1	Varlx Panamic	42.6	AO b'Active	58.3
Varlx Comfort	0.0	Sig Nav Precsn	13.0	Pentx AF Mini	41.9	Varlx Panamic	56.4
Ess Natural	0.0	Younger Image	12.5	HoyaLux ECP	41.1	Rdnstk Life AT	56.2
Zei Gradal Top	0.0	AO Pro 15	9.8	Pentx AF 150	41.0	Zei Gradal Top	55.6
HoyaLux ECP	0.0	Hoya GP Wide	9.4	Younger Image	40.8	Pentx AF Mini	54.9
SOLA XL	0.0	Pentx AF 150	8.7	AO Pro 15	40.0	AO Pro 15	49.5
Sig Nav Precsn	0.0	J&J Definity	5.4	Zei Gradal Top	35.0	Younger Image	45.3
SOLA Percepta	0.0	Ess Natural	0.0	J&J Definity	24.9	J&J Definity	12.8
Ess Spr No-lne	0.0	Zei Gradal Top	0.0	Ess Natural	20.0	Ess Natural	9.8

and viewed at 40 cm subtends 30 degrees horizontally and 37 degrees vertically. This represents a solid angle of 1,110 degrees^2—or 555 degrees^2 to fixate half of the page. Fixating either side of the page requires a near zone width of 15 mm, and being able to fixate half of the page requires 139 mm^2 of lens surface. The zone widths and areas of the lenses shown in Figures 8 and 9 are considerably smaller than these requirements; thus, larger numbers within the measured ranges represent greater abilities to fixate the task without head movement.

Another meaningful comparison is to an FT 28 bifocal. Allowing for 1.5-mm pupil clearance under the top of the segment, 1.5-mm clearance on each side, and extending to 3.5 mm below the optical center of the segment (i.e., the calculated area extends 3.5 mm above and 3.5 mm below the optical center of the segment), an FT 28 has a usable width of 25 mm and contains a total area of 175 mm^2, with a full add of +2.00. This width and area is considerably larger than provided by any of the PALs. The near zone of an FT 28 bifocal is also considerably higher than provided by any of the PALs. When a bifocal is fitted at the lower limbal margin, the top of the bifocal is only 5 to 6 mm below pupil center. Even if an additional 2 mm for pupil clearance are considered for below the line, the full bifocal add occurs at 7 to 8 mm below the pupil—much higher than the highest level of add appearance in PALs (as shown in Figure 7).

The utility of the near zone is dependent on the amount of the lower part of the lens that remains after edging (i.e., it depends on the fitting height in the frame). The near zone should, therefore, be evaluated down to the lowest usable portion of the lens for different fitting heights. The fitting height is the distance from the fitting cross to the lowest portion of the lens after edging. In order to relate the near zone measurements to usable near vision for a given fitting height, 2 mm are added to the Y values for each width measurement (because of the integration effects, this results in 1.5 mm added to the area measurements) to relate them to fitting height. The value of 2 mm was selected because it allows 0.5 mm extension of the lens into the frame bevel and another 1.5 mm to represent the mid-pupil location for a person with a 3-mm pupil. Therefore, this includes the entire lens, down to the lowest portion at which the eye can possibly use the lens.

Similar to the approach for distance and intermediate vision, a rating value equally weighted for zone width and zone area was determined. In reporting the near zone results, the Y dimension values were converted to fitting height values (as described earlier). Scalar values from 0 to 100 were determined for width of the +1.75 D near zone width (range, 0 to 15 mm) and for the near zone area (range, 0 to 100 mm^2). Final rating was a mean of the two. Ratings were established on the basis of the same ranges for all fitting heights in order that the rating would always represent the same amount of lens devoted to near vision, regardless of the fitting height. In this manner, near ratings are comparable across fitting heights. The ratings for near vision at different fitting heights are shown in Table 3.

Specialty usage

The ratings in Tables 2 and 3 are labeled "specialty usage" because the ratings are based on a single parameter. For wearers who have an overriding need for distance vision, intermediate vision, near vision, or reduced astigmatism, the rating value reports the magnitude of that particular attribute for a given lens (calculated as described earlier) in proportion to the others. The ratings in Tables 2 and 3 probably would be best utilized for wearers with such an overriding need for a par-

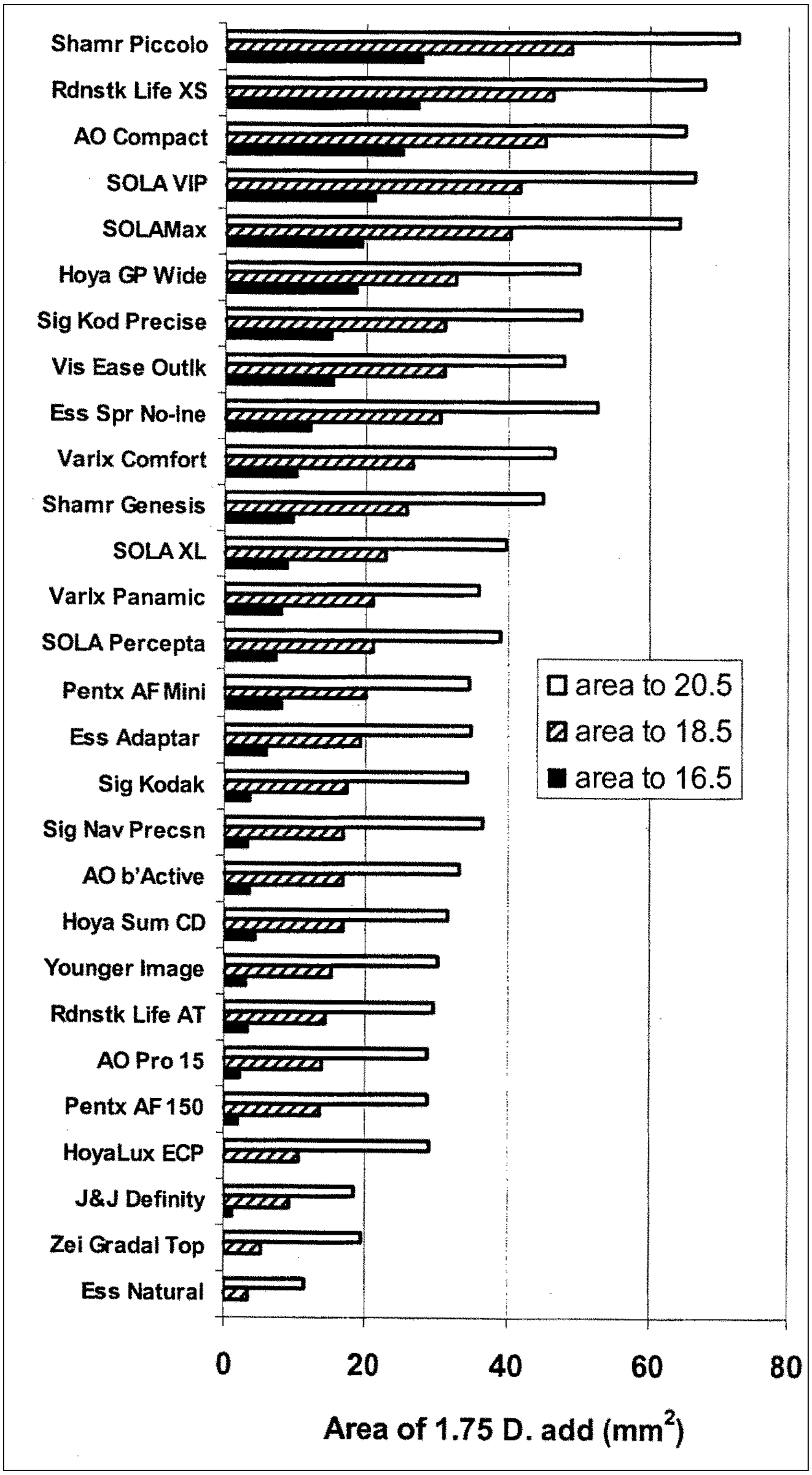

Figure 9 Cumulative area of the +1.75 D add (mm^2) to 16.5, 18.5, and 20.5 mm from the fitting cross—sorted by cumulative area to 18.5 m from fitting cross. Not all lenses had cumulative areas corresponding to the measured distances below the fitting cross.

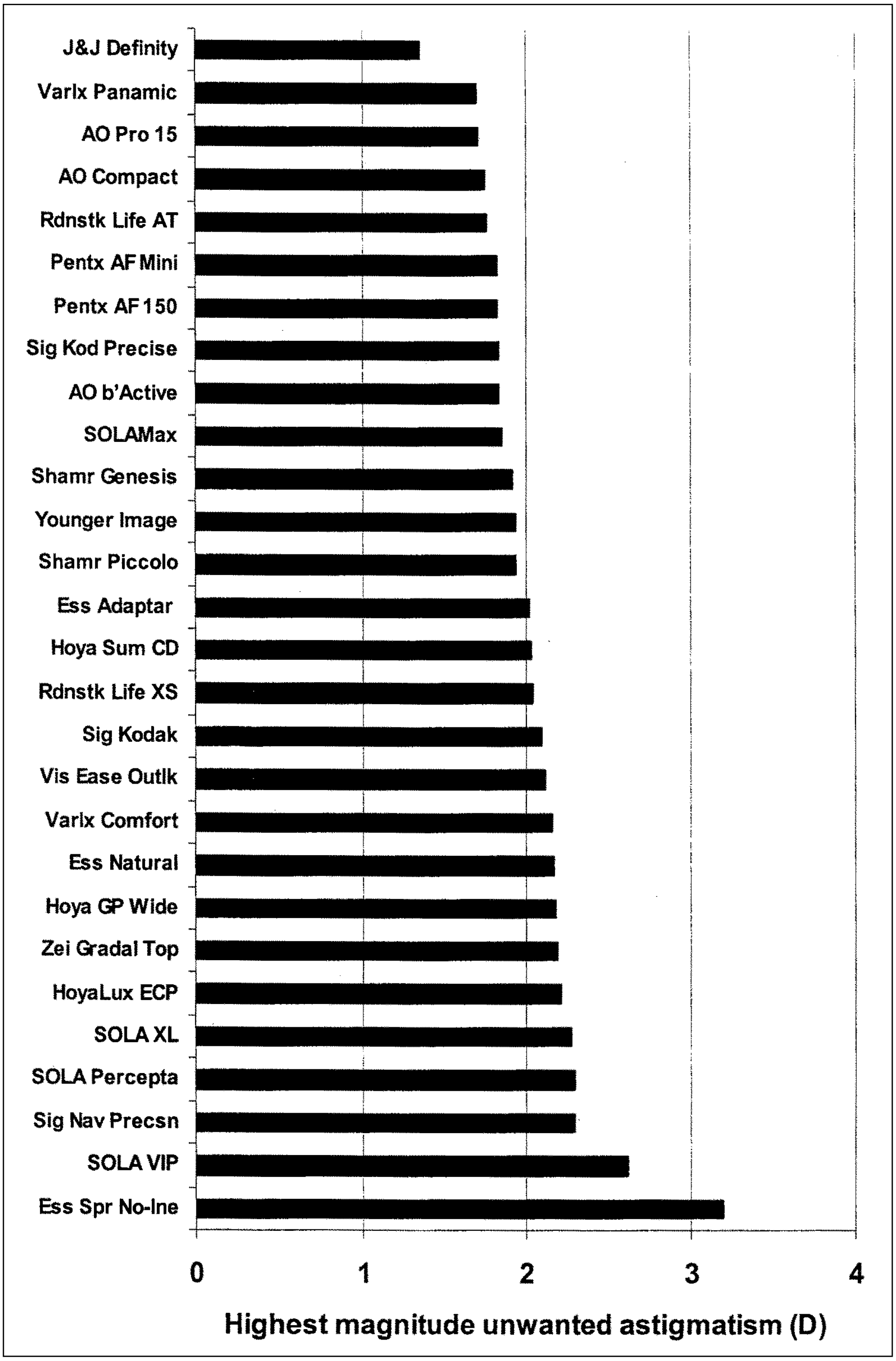

Figure 10 Highest magnitude of unwanted astigmatism measured on the lens.

ticular usage that the PAL is almost an alternative to a single-vision lens for distance, intermediate, or near—or they have an overriding need to reduce unwanted astigmatism. For example, a professional driver may have an overriding interest in wide and large distance vision. An emmetropic presbyope who intends to use the glasses as reading glasses might primarily be interested in a wide and large reading area, to the exclusion of other considerations.

Ratings for near vision (*see* Table 3) are dependent on the fitting height. Because the near zone ratings are calculated on the basis of the same ranges for width and area for all fitting heights, the ratings are comparable across fitting heights—i.e., the same rating number for one fitting height represents the same magnitude of near zone as it would for another fitting height. The ratings for the shorter fitting heights are not as great as those for higher fitting heights. Fitting any PAL with a short fitting height compromises the amount of near zone. Nonetheless, the values in Table 3 for shorter fitting heights indicate the lenses that provide the greatest width and area of near zone for those heights. Because the near zone width changes at different rates with height across lenses, the rating order of the lenses changes for different fitting heights.

Specialty usage combinations

The ratings in Table 4 are composites of selected ratings from Tables 1 and 2; the rating value reports the magnitude of that combination of attributes for a given lens (calculated as described earlier) in proportion to the other lenses. The distance/inter-

Table 4. Combination ratings for distance/intermediate, and for intermediate/near for a fitting height (FH) of 22 mm; ratings are presented with and without weighting for astigmatism

Specialty usage combinations							
Without astigmatism weighting				With 25% astigmatism weighting			
Distance and Intermediate	Rating	Inter and Near (FH 22)	Rating	Distance and Intermediate	Rating	Inter and Near (FH 22)	Rating
Zei Gradal Top	78.4	SOLAMax	75.4	J&J Definity	77.4	SOLAMax	71.4
Younger Image	74.2	Sig Nav Precsn	68.3	AO b'Active	69.2	J&J Definity	66.8
J&J Definity	72.1	Pentx AF Mini	64.5	Younger Image	69.1	AO Pro 15	64.0
AO b'Active	72.1	Rdnstk Life AT	63.1	Zei Gradal Top	68.1	Rdnstk Life AT	63.9
Shamr Genesis	71.3	Zei Gradal Top	63.1	Shamr Genesis	67.3	Pentx AF Mini	63.7
Sig Kodak	69.1	HoyaLux ECP	62.3	AO Pro 15	62.7	AO b'Active	60.0
HoyaLux ECP	65.5	AO Pro 15	62.3	Sig Kodak	62.6	Sig Nav Precsn	58.7
Vis Ease Outlk	60.6	Shamr Piccolo	60.0	HoyaLux ECP	58.0	Shamr Piccolo	58.5
AO Pro 15	60.5	AO b'Active	59.8	Vis Ease Outlk	56.0	Zei Gradal Top	56.7
SOLA Percepta	59.4	Sig Kodak	58.7	Varlx Panamic	54.8	Shamr Genesis	56.2
Ess Natural	57.7	Hoya GP Wide	58.5	Rdnstk Life AT	54.1	Varlx Panamic	56.0
Sig Nav Precsn	56.9	Hoya Sum CD	58.3	Pentx AF Mini	54.1	HoyaLux ECP	55.6
Pentx AF Mini	51.7	J&J Definity	58.0	Pentx AF 150	53.8	Hoya Sum CD	55.6
Pentx AF 150	51.3	Shamr Genesis	56.5	Ess Natural	52.9	Sig Kodak	54.8
Rdnstk Life AT	50.1	SOLA VIP	56.0	SOLA Percepta	52.0	Hoya GP Wide	53.4
Hoya Sum CD	50.1	SOLA XL	55.2	Sig Nav Precsn	50.2	AO Compact	53.3
Varlx Panamic	49.7	Ess Adaptar	52.9	Hoya Sum CD	49.4	Pentx AF 150	52.9
Ess Adaptar	48.6	Varlx Panamic	51.4	Ess Adaptar	48.5	Sig Kod Precise	52.5
Ess Spr No-lne	47.0	Varlx Comfort	51.2	SOLAMax	46.3	Ess Adaptar	51.7
SOLA XL	43.3	Younger Image	50.9	Sig Kod Precise	45.0	Younger Image	51.7
SOLAMax	41.9	Pentx AF 150	50.1	Hoya GP Wide	40.4	SOLA XL	49.2
SOLA VIP	41.9	Sig Kod Precise	49.8	SOLA XL	40.3	Rdnstk Life XS	49.0
Hoya GP Wide	41.2	Rdnstk Life XS	49.7	Rdnstk Life XS	39.9	Varlx Comfort	48.2
Varlx Comfort	40.1	AO Compact	48.9	Varlx Comfort	39.9	Vis Ease Outlk	46.5
Sig Kod Precise	39.8	Vis Ease Outlk	48.0	Shamr Piccolo	38.4	SOLA VIP	44.0
Rdnstk Life XS	37.7	SOLA Percepta	40.4	AO Compact	37.5	Ess Natural	39.9
Shamr Piccolo	33.1	Ess Natural	40.4	SOLA VIP	33.4	SOLA Percepta	37.8
AO Compact	27.7	Ess Spr No-lne	37.0	Ess Spr No-lne	27.9	Ess Spr No-lne	20.4

mediate rating is comprised (in equal parts) of those individual ratings from Table 2. Similarly, the distance/near rating in Table 4 is a composite of those two individual values. The near ratings for a fitting height of 22—which is a higher fitting—are used in this composite because anyone who has special intermediate/near visual needs probably will benefit from the near zone advantages of a higher fit.

The two composite ratings in Table 4 are shown with and without inclusion of 25% weighting of the unwanted astigmatism for each lens. The value of 25% was selected because it places equal emphasis on the astigmatism value with the distance, intermediate, and near zone ratings. The same weighting value for astigmatism is used consistently throughout this analysis, because the effects of unwanted astigmatism probably are the same, regardless of the lens usage category.

The distance/intermediate ratings in Table 4 indicate lenses that probably would be best used for wearers whose tasks are primarily at distance and intermediate and whose needs for near vision are limited. This could include many wearers who are professional drivers or are engaged in physical outdoor activities. The intermediate/near rating indicates lenses that have larger and wider intermediate and near zones, with no consideration of the distance zone. Wearers who would benefit most from these lenses would be those with extended viewing needs in indoor environments with minimal distance needs. These could also work well for emmetropic presbyopic wearers who intend to use the lenses primarily for near/intermediate activities and would remove the lenses for distance activities.

General usage combinations

The ratings in Tables 5 and 6 are distance/intermediate/near and distance/near composites.

Table 5. General usage combination ratings—no weighting for unwanted astigmatism; ratings calculated for fitting height (FH) of 18 and 22—representative of low and high fitting heights, respectively

General usage combinations—no astigmatism weighting

Distance, Inter & Near (FH 18)	Rating	Distance, Inter & Near (FH 22)	Rating	Distance and Near (FH 18)	Rating	Distance and Near (FH 22)	Rating
Shamr Genesis	56.1	Shamr Genesis	65.6	Ess Spr No-lne	56.5	Ess Spr No-lne	73.3
Younger Image	53.6	Zei Gradal Top	63.9	Shamr Genesis	54.7	SOLA Percepta	69.1
AO b'Active	52.9	Younger Image	63.1	SOLA Percepta	54.4	Shamr Genesis	68.9
Zei Gradal Top	52.2	AO b'Active	63.0	Vis Ease Outlk	53.8	Vis Ease Outlk	64.6
Sig Kodak	50.8	Sig Kodak	61.5	Younger Image	49.9	Younger Image	64.1
Vis Ease Outlk	50.5	Vis Ease Outlk	57.7	Rdnstk Life XS	44.0	SOLA VIP	62.0
J&J Definity	49.9	HoyaLux ECP	57.4	SOLA VIP	43.3	Rdnstk Life XS	59.8
HoyaLux ECP	48.8	J&J Definity	56.4	AO b'Active	42.0	AO b'Active	57.0
SOLA Percepta	46.5	SOLA Percepta	56.3	Sig Kodak	40.6	Sig Kodak	56.7
AO Pro 15	43.6	Sig Nav Precsn	55.3	Shamr Piccolo	34.1	Zei Gradal Top	50.2
Sig Nav Precsn	42.3	AO Pro 15	53.6	Sig Kod Precise	33.0	Shamr Piccolo	49.9
Ess Spr No-lne	41.3	SOLA VIP	53.3	Zei Gradal Top	32.7	Sig Kod Precise	47.3
Pentx AF Mini	41.2	SOLAMax	52.6	AO Compact	32.4	Varlx Comfort	45.8
Hoya Sum CD	41.1	Ess Spr No-lne	52.4	HoyaLux ECP	31.5	AO Compact	44.8
SOLA VIP	40.9	Rdnstk Life XS	49.1	Varlx Comfort	30.7	HoyaLux ECP	44.3
SOLAMax	40.7	Hoya Sum CD	48.9	Varlx Panamic	30.4	Pentx AF 150	42.2
Varlx Panamic	40.3	Pentx AF Mini	48.4	J&J Definity	29.2	Hoya GP Wide	41.8
Ess Adaptar	39.0	Rdnstk Life AT	48.0	Ess Adaptar	27.5	Varlx Panamic	40.9
Rdnstk Life XS	38.5	Pentx AF 150	47.9	Ess Natural	27.3	SOLAMax	40.6
Ess Natural	38.5	Shamr Piccolo	47.7	Hoya Sum CD	26.6	Sig Nav Precsn	40.6
Rdnstk Life AT	37.8	Varlx Panamic	47.3	Pentx AF 150	26.1	Ess Adaptar	39.6
Shamr Piccolo	37.1	Hoya GP Wide	47.2	SOLA XL	23.8	J&J Definity	39.0
Pentx AF 150	37.1	Ess Adaptar	47.1	AO Pro 15	23.1	Hoya Sum CD	38.4
SOLA XL	36.4	Varlx Comfort	45.7	SOLAMax	22.7	AO Pro 15	38.2
Sig Kod Precise	36.1	Sig Kod Precise	45.6	Sig Nav Precsn	21.1	Ess Natural	37.3
Varlx Comfort	35.6	Ess Natural	45.1	Pentx AF Mini	18.2	SOLA XL	36.8
AO Compact	32.2	SOLA XL	45.1	Hoya GP Wide	17.0	Rdnstk Life AT	30.6
Hoya GP Wide	30.6	AO Compact	40.5	Rdnstk Life AT	15.3	Pentx AF Mini	29.0

The composite ratings represent equal weightings of the components from Tables 1 and 2. The composite ratings are calculated for component near fitting heights of 18 and 22—representative of shorter and higher fitting heights respectively. The ratings in Table 5 do not include weighting for astigmatism, whereas those in Table 6 include a 25% weighting of the astigmatism component.

The general usage ratings in Tables 5 and 6 indicate lenses that probably would be best used for wearers who perform tasks at a variety of working distances. The particular ratings that best apply are dependent on whether intermediate is important, the fitting height of the lens, and whether unwanted astigmatism is a factor in lens acceptance or performance for the particular user.

General discussion

Fixation of an object can be accomplished by eye movement, head movement, or a combination of the two. The previously discussed task analyses, based solely on eye movement, indicate that PALs provide a narrower and smaller field of fixation than that required by common tasks. Previous research,[9] however, shows that the normal extent of eye movements is greater than the eye movement requirements of the tasks that have been analyzed. Therefore, the analyses indicate that PALs limit the extent of eye fixations that would normally be used for these tasks. This conclusion is also supported by research that shows that PAL wearers increase the amount of head movement and decrease the amount of eye movement used to view a task.[10] Selenow et al.[11] tested visual performance with PALs compared to single-vision lenses on four computer-based tasks. They found statistically significant better performance with single-vision lenses on one task, but not the others, and concluded that PALs showed "marginally diminished" performance compared to single vision lenses. It appears that

Table 6. General usage combination ratings—25% weighting for unwanted astigmatism; ratings calculated for fitting height (FH) of 18 and 22—representative of low and hight fittings heights, respectively

General usage combinations—25% astigmatism weighting

Distance, Inter & Near (FH 18)	Rating	Distance, Inter & Near (FH 22)	Rating	Distance and Near (FH 18)	Rating	Distance and Near (FH 22)	Rating
J&J Definity	60.7	J&J Definity	65.6	Shamr Genesis	54.8	Shamr Genesis	65.5
Shamr Genesis	55.9	Shamr Genesis	63.0	Younger Image	50.9	Younger Image	61.6
AO b'Active	54.8	AO b'Active	62.4	Vis Ease Outlk	50.8	SOLA Percepta	59.3
Younger Image	53.7	Younger Image	60.8	SOLA Percepta	48.3	Vis Ease Outlk	58.9
AO Pro 15	50.0	AO Pro 15	57.6	AO b'Active	46.6	AO b'Active	57.9
Sig Kodak	48.9	Zei Gradal Top	57.3	J&J Definity	45.3	Rdnstk Life XS	56.5
Zei Gradal Top	48.5	Sig Kodak	56.9	Rdnstk Life XS	44.7	Sig Kodak	53.4
Vis Ease Outlk	48.4	SOLAMax	54.3	Sig Kodak	41.3	J&J Definity	52.5
Varlx Panamic	47.8	Vis Ease Outlk	53.8	AO Compact	40.9	Shamr Piccolo	50.9
Pentx AF Mini	46.2	Varlx Panamic	53.0	Varlx Panamic	40.3	Sig Kod Precise	50.6
HoyaLux ECP	45.5	Rdnstk Life AT	52.5	Sig Kod Precise	39.9	AO Compact	50.2
SOLAMax	45.4	HoyaLux ECP	51.9	Shamr Piccolo	39.1	SOLA VIP	48.5
Rdnstk Life AT	44.8	Pentx AF Mini	51.6	Ess Spr No-lne	35.1	Varlx Panamic	48.2
Pentx AF 150	43.2	Pentx AF 150	51.2	Pentx AF 150	34.9	Ess Spr No-lne	47.6
Hoya Sum CD	42.7	SOLA Percepta	49.7	AO Pro 15	34.6	Pentx AF 150	47.0
SOLA Percepta	42.4	Sig Kod Precise	49.4	SOLA VIP	34.5	Zei Gradal Top	47.0
Sig Kod Precise	42.2	Shamr Piccolo	49.3	Zei Gradal Top	33.9	AO Pro 15	46.0
Shamr Piccolo	41.3	Sig Nav Precsn	48.9	Varlx Comfort	32.8	SOLAMax	45.3
Ess Adaptar	41.2	Hoya Sum CD	48.5	Ess Adaptar	32.6	Varlx Comfort	44.2
AO Compact	40.8	Rdnstk Life XS	48.5	HoyaLux ECP	32.4	HoyaLux ECP	42.0
Rdnstk Life XS	40.6	Ess Adaptar	47.3	SOLAMax	31.9	Ess Adaptar	41.7
Sig Nav Precsn	39.2	AO Compact	47.0	Hoya Sum CD	31.8	Hoya GP Wide	40.9
Ess Natural	38.5	Hoya GP Wide	44.9	Ess Natural	30.2	Hoya Sum CD	40.6
Varlx Comfort	36.5	Varlx Comfort	44.1	Pentx AF Mini	29.0	Rdnstk Life AT	39.5
SOLA XL	35.2	Ess Natural	43.5	Rdnstk Life AT	28.0	Sig Nav Precsn	37.9
SOLA VIP	32.6	SOLA VIP	42.0	SOLA XL	25.7	Ess Natural	37.6
Hoya GP Wide	32.4	SOLA XL	41.6	Sig Nav Precsn	23.3	Pentx AF Mini	37.1
Ess Spr No-lne	23.6	Ess Spr No-lne	32.0	Hoya GP Wide	22.2	SOLA XL	35.4

wearers probably adapt quite well to the limited vision zones of PALs by using more head movements, but small performance decrements remain.

The optical measurements show wide variations in PAL design. For most of the distance, intermediate, and near variables measured in this study, there was more than a 2:1 range of values across lenses. Selecting a lens that provides greater width and area for a particular viewing distance will enable the wearer to clearly view the task with more eye movement and less head movement. This seems desirable because it is a closer match to normal eye fixation magnitudes and would require less of a shift to head movements.

Trade-offs in lens design are apparent—designs that rate high in one or two zones often are rated lower in others. The rating magnitudes of the general usage categories (*see* Tables 5 and 6) are lower than those in the other Tables, because there is a leveling effect when all categories are included in a composite rating. No single design can excel in all areas: distance, intermediate, near, and reduced astigmatism.

As a direct result of the trade-offs in design and the fact that the various designs use different trade-offs, some designs can be expected to provide better vision at distance, intermediate, near, or various combinations of those distances. Unwanted astigmatism can also be factored into the rating. Concomitantly, all patient visual needs are not the same. The categorical ratings provided in Tables 2 through 6 list the lenses that provide the widest and largest areas of clear vision for the various individual or composite zones. These Tables can be used to identify those lenses that can best meet the specific visual needs of particular patients. Just as there is a range of optical characteristics among PALs, there is also a range of visual needs among patients. The clinical task is to match the two.

The rating scales developed in this study are based on viewing zone width and area measurements. They have been validated insofar as the widths and areas provided by the lenses are less than normal eye fixation movements and also less than the calculated eye fixation requirements of common tasks. Therefore, it can be expected that lenses with greater widths and areas will provide better vision. The rating scales were primarily developed in this study as a means to integrate the sizes of more than one viewing zone and to integrate the effects of unwanted astigmatism with viewing zone sizes. Several assumptions have been made leading to the development of the ratings: refractive errors of 0.25 DS or 0.50 DC (with respect to prescription of) have been used as viewing zone limits; the area and width of a viewing zone have been weighted equally in calculating a rating, resulting in the horizontal dimension having twice the weight of the vertical; unwanted astigmatism has been weighted 25% compared to 75% for viewing zone width/area; the upper (100) and lower (0) limits of the scales have generally been selected on the basis of the range of measurements obtained in this study. Most of these assumptions have not been previously addressed by research. The rating scales are linear insofar as the rating value is directly related to the measure of which it is composed—i.e., doubling the area/width doubles the rating value. The relationships between rating zone width/area and performance or patient satisfaction, however, are not known; thus, the relationships between the rating factor and performance/satisfaction are not known. Data are not available to relate these ratings to task performance, patient acceptance, or patient satisfaction. Further research is required for such validation.

The ratings and the data from which they have been derived are based on state-of-the-art measurements, and the assumptions used are considered the most-reasonable ones, given our knowledge of PALs and the visual system. It is likely that future improvements can be made, however, and the potential limitations must be considered. First of all, only one lens of each design was measured. Ideally, lens manufacture would be highly consistent, so that all lenses of the same design are identical. However, inconsistencies are very possible, and better design representation might be attained by measuring and averaging multiple lenses. It is also possible that other derivatives of the optical measurements—such as prism magnitude or axis, measures of optical distortion, or higher order aberrations—could meaningfully represent performance. Binocular aspects of wearing PALs, such as corridor angle or prismatic difference between the eyes, have not been evaluated, but these factors also can be expected to affect vision performance. In addition, several assumptions have been made concerning the values selected to represent the borders of the distance, intermediate, and near zones; the relative importance of vertical vs. horizontal dimensions; and the relative importance of unwanted astigmatism. Each of these issues has been discussed earlier in this article. Future research, advances in measurement technology, and other future findings probably will provide better approaches and may indicate changes in the assumptions.

Conclusions

Large variations exist in the optical properties of PAL designs. Measurements and analyses clearly indicate that some designs, based on their optical properties, provide better distance zones, intermediate zones, near zones, or reduced astigmatism. The magnitudes of PAL zone widths and areas have also been shown to be smaller than the eye fixation demands of those tasks—assuming no adaptive head movements. The lenses with better optical characteristics in the distance, intermediate, or near zone will enable a wearer to have a wider and larger area of the task that can be fixated at that viewing distance without head movement. The results and analyses presented in this study can be used to select particular lens designs that will optimally meet the specific visual needs of the individual patient. It is also hoped that the findings presented in this study will serve as a stimulus for further research and for the ophthalmic industry to develop and market PAL designs specific to visual needs.

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Corresponding author:

James E. Sheedy, O.D., Ph.D.
The Ohio State University
College of Optometry
320 West Tenth Avenue
P.O. Box 182342
Columbus, Ohio 43218-2342

jsheedy@optometry.osu.edu