Peripheral Design of Progressive Addition Lenses and the Lag of Accommodation in Myopes

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Purpose. Insufficient accommodative response is assumed to result in myopia progression. We have investigated if the accommodative lag in myopes is different between a single vision lens (SVL) and the progressive addition lens PAL 2, clinically trialled for its ability to reduce progression of myopia, and if there exist differences in accommodative lag between PAL 2 and other PALs with the same addition power (+1.50 D).

Methods. The influence of spherical SVL and four different designs of PALs that differ in the near zone width (PAL 1) or that have different signs and magnitude of horizontal gradients of mean power adjacent to their near vision zones (PAL 3 and PAL 4) on the accommodative response was investigated for different near viewing distances (40, 33, and 25 cm) in 31 subjects, aged 18 to 25 years.

Results. The SVL correction resulted in insufficient accommodative response for the near object viewing distances tested. PAL 2 did significantly reduce accommodative lag for all near object distances tested. The PAL design with a more negative horizontal mean power gradient (PAL 4) provided a lower lag of accommodation when compared with PAL 2 at the shortest object distance of 25 cm (P = 0.05) and was able to reduce the lag of accommodation to a level below the depth of focus for the higher near working distances tested.

Conclusions. Designs of PAL with more negative horizontal mean power gradients are the most effective in lowering the lag of accommodation in myopes. This could make them good test candidates for myopia control applications.

Keywords: myopia, refractive error, lag of accommodation, lens

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evidence of effect saturation after 12 months. In earlier days, standard progressive lenses with long corridor lengths developed for presbyopes have been used.\textsuperscript{18, 19} Later on, new PAL designs adapted for juvenile use with shorter corridors, making it easier for children to access the addition power, have been developed and tested.\textsuperscript{21 - 24} Hasebe et al.\textsuperscript{22} investigated the influence of the addition power and the positive asphericization of the distance zone of the PAL on their efficacy to provide retardation of myopia progression. The positive asphericization of the distance zone did not retard myopia and a minimum of +1.50 D addition was required to get an initial efficacy of 30% in the first year.

The purpose of the study was to establish the influence of the design of a PAL on the reduction of the LA by using different widths of the near zone and varying the horizontal power gradients in the immediate vicinity of the near zone of a lens. Assuming the accommodative stimulus is spatially averaged in some way, the expectation was to have greater power gradients in the immediate vicinity of the near zone compared to the conventional PALs (see the optical mean addition power contour plots of PAL 3 in Figs. 1, 2). The design has a relatively high astigmatism in the periphery due to this unusual power distribution. This design was implemented with a progressive back surface and a spherical front surface.

The third new test design, labelled PAL 4, has a 13-mm corridor length with a wide distance zone and a relatively narrow near zone surrounded by areas having the mean optical power close to the power of the distance zone. Consequently, the design has relatively large negative horizontal gradients of mean power around the near zone. It also has relatively large values of peripheral astigmatism in some peripheral areas due to the presence of high power gradients. The progressive surface providing the optical power progression was implemented on the back side of the lens.

Measurement of Refractive Errors
Objective as well as subjective refraction was measured prior to the course of the study. Autorefration was measured for a pupil diameter of 3 mm using a wavefront aberrometer (i.profiler Plus, Carl Zeiss Vision GmbH, Aalen, Germany). Subjective refraction was measured under natural pupil conditions, using a Subjective Refraction Unit (SRU; Carl Zeiss Vision GmbH).

After the subjective measurement of the sphero-cylindrical refraction errors, the dominant eye of each participant was determined using the pinhole test.\textsuperscript{25} We fitted the progressive lenses into a custom developed frame, where the height and the pupillary distance were adjustable (Engelhardt Eyewear Pty Ltd., Richmond, SA, Australia).

Correction of Refractive Errors and Lens Design
The trial included a single vision spherical lens (SVL) and 4 PAL designs. One of the PAL designs was used as a benchmark with a known myopia control efficacy. This was a +1.50 D addition progressively aspherized (PA) PAL trialed for 2 years on the Asian 6- to 12-year-old myopes, having a corridor of 14 mm in length measured from the fitting cross (FC) to the near reference point (NRP).\textsuperscript{21} The ability of this lens to reduce the LA was not known prior to the study. This lens was called PAL 2 in the trial and was used as a benchmark against which the ability of other lenses to reduce the LA was judged. It has a progressive surface on the front of the lens and a prescription surface on the back side. The first of the new designs tested, labelled PAL 1, was derived from PAL 2 and also had the +1.50 D addition. The positive asphericization of the distance zone of PAL 2 was removed. Then its corridor length was shortened and the distance–near zone size balance transformed. The aim of the design modifications was to provide a much wider zone for clear distance vision and a higher and narrower near zone. The corridor length was changed to 12 mm, and the new zone size balance adjustment was achieved by rotating the distance zone boundaries down by 24° with the corresponding rotation in the inward direction for the near zone boundaries. The design was implemented on the back surface of the lens configured to provide both the prescription and addition power, with the front surface being spherical.

The second new design, labelled PAL 3, has a +1.50 D addition with a 13-mm corridor length, and a moderately wide distance and near zones. Its unique feature is the design of the periphery, which has a reversed sign (positive) horizontal mean power gradient adjacent to the near zone compared to the conventional PALs. The design has a relatively high astigmatism in the periphery due to this unusual power distribution. This design was implemented with a progressive back surface and a spherical front surface.
Japan). The filter was also fitted into the test frame. Refractive errors were measured for distances of 25 cm (4 D dioptric object distance), 33 cm (3 D dioptric object distance), and 40 cm (2.5 D dioptric object distance), as well as for distance vision (400 cm). For each combination of spectacle lens and distance, five individual readings of sphere, cylinder, and axis were obtained. The sequence of testing (# spectacle lens and distance) was randomized between the subjects. During near vision, the subjects were asked to look at an acuity chart and to fixate the lowest line of optotypes. Prior to the measurement and while accommodation for the different distances was measured, the examiner controlled subjectively the alignment of the near point of the spectacle lens and the subject’s eye in order to ensure that the subjects looked through the NRP. This inspection was done by checking if the NRP of the spectacle lens was in one line with the eye of the subject and that the acuity chart was on the same height as the NRP and the eye, for every target distance. All far distance measurements of the spherical error were corrected by 0.25 D since the measurements were done at 400 cm distance. The individual readings were transformed into the power vector components of refraction (M, J0, and J45) and averaged.

**Calculation of the LA**

The different object distances were defined relative to the corneal plane, while the setup of the autorefractor was configured to calculate the measured refractions with the lens 12 mm in front of the corneal plane (equal to the vertex distance [VD]). The following formulae were used to calculate the AR, accommodative demand (AD), and LA at the corneal plane:

\[
\text{LA} = \frac{\text{AR}}{\text{AD}}
\]

**FIGURE 1.** The ray traced optical astigmatism and optical mean addition power distributions for the four PAL designs tested. The contours are displayed over the circular zone of 50 mm diameter in the lens front surface scan coordinates.

**FIGURE 2.** The contour plots of the mean power error distribution on the reference plane in the object space for each of the four PALs and three near target distances tested. The ray tracing has been carried out on the perfectly accommodating static eye gazing at the center of the target stimulus marked by the intersection of the gray lines. The extent of the object field is 185 mm horizontally and 170 mm vertically.
Lag of Accommodation in Myopes Wearing PALs

The following formulae from Atchison and Varnas\(^27\) were used: formula \(8b\) = formula 1, \(AR\); formula \(5d\) = formula 2, \(AD\). For \(AR\) (Equation 1), \(GS(SV)\) is the Grand Seiko measured sphere equivalent refraction of the occluded nondominant eye when the dominant eye is wearing a SVL and viewing a target at a distance of 400 cm. \(GS(PAL-Near)\) is the measured Grand Seiko sphere equivalent refraction of the nondominant eye when the other eye is looking through the NRP of a PAL viewing a target at one of the closer object distances. In formula (2), \(Rx\) is the sphere equivalent of the subjective refraction for distance objects, \(DT\) is the object distances. In formula (3), \(LA\) is the accommodation lag.

\[
AR = \frac{GS(SV) + 0.25}{1 - VD[GS(SV) + 0.25]} - \frac{GS(PAL-Near)}{1 - VD \cdot GS(PAL-Near)}
\]

\[
AD = \frac{Rx}{1 - VD \cdot Rx} - \frac{1 + (DT + VD)(Rx + ADD)}{DT - VD(DT + VD)(Rx + ADD)}
\]

\[
LA = AD - AR
\]

The following table shows the ARs, LAs, and standard errors for the 40-, 33-, and 25-cm object distances from the eye.

<table>
<thead>
<tr>
<th>Object Distance, 40 cm</th>
<th>Object Distance, 33 cm</th>
<th>Object Distance, 25 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AR</td>
<td>LA</td>
</tr>
<tr>
<td>SVL</td>
<td>1.75</td>
<td>0.60</td>
</tr>
<tr>
<td>PAL 1</td>
<td>0.85</td>
<td>0.15</td>
</tr>
<tr>
<td>PAL 2</td>
<td>0.85</td>
<td>0.15</td>
</tr>
<tr>
<td>PAL 3</td>
<td>0.72</td>
<td>0.27</td>
</tr>
<tr>
<td>PAL 4</td>
<td>0.91</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Statistics

Two main hypotheses were formulated before the trial: (1) Narrower near zones lead to lower lags of accommodation, and (2) the high negative horizontal power gradients adjacent to the near zone will provide the maximum reduction of accommodative lag.

Statistical analyses were performed in R (The R Foundation for Statistical Computing). Exploratory data analysis revealed significant deviations from the normal distribution, as well as the presence of outliers in a range of data sets. Since each subject has been measured with five different lenses at four target object distances, these data sets cannot be regarded as independent. Violation of data independence makes the use of ANOVA analysis inappropriate. Therefore, we applied a robust or nonparametric hypothesis testing method for paired data. A 1-tailed Mann-Whitney \(U\) test with an appropriately formulated alternative hypothesis was employed.

Results

Baseline AR With Single Vision Correction and Progressive Addition Lenses

Subjects were wearing SVL or PALs correcting their sphero-cylindrical refractive error of the dominant eye, which was fixating on three different near viewing targets at distances of 40, 33, and 25 cm, while the consensus AR was measured in the nondominant eye occluded by the infrared-transparent filter. The LA in the spectacle plane was calculated using formulae 1 to 3, and the Table shows the ARs, LAs, and standard errors of the LA.

Statistical analysis using the Mann-Whitney \(U\) test revealed significant differences for the LA between 40 and 25 cm \((P < 0.001)\), as well as between 25 and 33 cm \((P < 0.001)\), but not for the comparison of 40 versus 33 cm \((P = 0.06)\), in case the SVL were used.

The Lag of Accommodation for the Benchmark PAL and Comparison to SVL

In order to test if the benchmark PAL (PAL 2) reduces the LA during near work when compared to the SVL, a statistical analysis was run to compare the LA. The null hypothesis was that the mean LA for each of the near object distances tested with PAL 2 was the same as that with the SVL. When making these analyses, it was ensured that the alternative hypothesis was the same as independent. The alternative hypothesis was that the SVL showed greater LA than the PAL 2. To test this, a “greater-than” alternative hypothesis \([i.e., LA(SVL) > LA(PAL 2)]\) was needed instead of a “two-sided” alternative hypothesis. Using the Mann-Whitney \(U\) test, it was found that SVL causes greater LA than PAL 2 at all object distances \((P < 0.001)\) in all cases.

Testing the Hypotheses

In order to test the hypotheses, the lags of accommodation with the different PALs were tested against the defined benchmark. The Mann-Whitney \(U\) test with properly formulated one-sided alternative hypothesis for each of the comparisons was used to test the statistical significance of the differences between the lags. The alternative hypotheses in comparisons between the PALs followed the rationale of the formulated primary and secondary hypotheses: the PALs with narrower near zones are expected to give smaller lags of accommodation and PALs with lesser positive gradients or more negative gradients are expected to ensure smaller lags of accommodation.

Statistical analysis revealed the following: PAL 1 did not have less LA than PAL 2 for any object distance at the 5% confidence level but has shown a trend for the 25-cm object distance \((P = 0.07)\). PAL 3 had a higher LA than PAL 2 for all object distances \((P < 0.05)\). PAL 4 had a lower LA than PAL 2 for the 25-cm object distance \((P < 0.05)\), but the effect lost significance for larger object distances \((P = 0.08\) and \(P = 0.17\) for the 33-cm and 40-cm object distances, respectively). For details, see Figure 3.
The current study investigated the efficiency of a progressive addition lens design on the reduction of the LA, a known risk factor for the development as well as progression of myopia. The results suggest that negative horizontal mean power gradients adjacent to the near vision zone of a PAL enhance a reduction in the LA due to addition power in a young myopic study group.

Baseline LA Using Single Vision Spectacle Lenses

Using SVLs to correct the individual spherocylindrical refractive errors, the LA (mean ± SD) increased with an increasing AD (2.5 D: 0.6 D ± 0.5 D; 3.0 D: 0.6 D ± 0.5 D; 4.0 D: 0.9 D ± 0.5 D). Variable amounts of the LA have been found among different studies. Mean lags of accommodation in myopic children and young adults, corrected for their distance vision, for the 33-cm target object distance include 0.6 D, 28 1 D to 1.3 D, 29 and up to 1.5 D. 30 Our mean value at this distance with the SVL of 0.6 D is on the low side of the range but matches Tarrant, 28 which is the only study among those listed above that was measuring young adults.

LA With SVL Distance and Near Correction

Berntsen et al. 3 investigated the influence of the type of correction (SVL or SVL with 2.0 D add power) on the LA in 85 myopic children that had high lags of accommodation for a 4-D Badal stimulus (mean age ± SD: 9.9 ± 1.3 years). The correction of myopia with SVL resulted in a LA of 1.7 ± 0.4 D, while the SVL with +2.00 D add power reduced the lag by 0.5 ± 0.3 D. Measuring the LA with SVL in 29 Chinese myopic children, 29 a reduction of the LA with a 1.5-D add on the SVL to 0.7 (SD: ± 0.5 D) was found, while the lag with the SVL was 1.0 D (SD: ± 0.7 D). Investigating the influence of 2.0 D add power on the accuracy of accommodation in myopic and emmetropic children, Sreenivasan et al. 32 observed that the +2.0 D addition lenses eliminated the lags of accommodation in myopic children during natural viewing conditions.

Benchmark PAL and SVL

PAL 2 has been used already in a clinical trial to investigate its efficacy in reducing progression of myopia in children. 31 There was a statistically significant (P = 0.02) retardation of myopia progression (0.27 ± 0.11 D, equivalent to a reduction ratio of 20%) during the 24-month period of the trial (0.24 D of which has occurred in the first 12 months) for the positively aspherized PAL with the 1.5 D of add power, when compared with a SVL control group. 31 The reduction of myopia progression using the PA-PAL and 1.50 D add power was within the range of reported retardations of myopia from earlier trials that used standard PALS. Standard single vision spherical lenses lead to higher lags of accommodation than the benchmark lens, indicating that the progressive addition lens is effective in the reduction of the LA.

Test of the Two Hypotheses

The ray tracing of test designs for the static eye viewing near targets at the studied range of object distances has revealed that the current study did not succeed in separating the test lens designs into pairs that differ in the width of the near zone only. Lens design PAL 1 has not only a narrower near zone than PAL 2 but also has higher negative horizontal mean power gradients than PAL 2, especially for the 25-cm object distance. Since PAL 1 did not show a statistically significantly different LA from PAL 2 at any object distance, despite some differences in power gradients on top of the near zone width differences, it is most likely that hypothesis #1 is incorrect—narrower near zones in PALS are unlikely to lead to lower LA.

Our results suggest that accommodation responses, when looking at near objects through the center of the near zone of PALs, depend not just on the addition power of the lens but also on the distribution of the peripheral power in the lower viewing zone of the lens, and that the designs with the more negative horizontal mean power gradient lead to a lower LA, especially compared to those with the positive horizontal mean power gradient (the LA with PAL 4 was significantly [P < 0.005] smaller for all three object distances when compared to PAL 3). The conventional progressive lens (PAL 2) reduced the LA by approximately 40% to 75% when compared to the SVL, depending on the object distance. PAL 4 appears to further reduce the LA 30% more than conventional PAL.

LA and Depth of Focus

When selecting the optimal PAL design for the retardation of myopia progression, one can hypothesize that the LA should be reduced below the depth of focus, which has been reported to be approximately ±0.3 D. 33 In the set of PALS in the current study, this is satisfied by PAL 4 for the near distances down to 33 cm, but none of the tested PALS was able to do this for the closest object distance tested (25 cm) that some children may also use, especially when working with small electronic devices like hand-held video game devices.

CONCLUSIONS

The current study suggests that accommodation responses using PALS are dependent on the addition power and on the distribution of the peripheral power in the lower viewing zone of the lens. Whether this may have an impact on the rate of myopia retardation needs to be tested in a clinical trial. Measuring the children’s ARs when viewing near targets through the lower viewing zone of those lenses would also test the longer term adaptation of the accommodation system to addition power and will hopefully shed some light on the saturation of efficacy of PALS in the reduction of the progression of myopia.
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References


