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ORIGINAL ARTICLE

Optimal Dioptric Value of Near Addition Lenses Intended to Slow Myopic Progression

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ABSTRACT

Purpose. The purpose of this study was to determine the optimal power value of near addition lenses, which would create the least error in accommodative and vergence responses.

Methods. We evaluated accommodative response, phoria, and fixation disparity when the subject viewed through various addition lenses at three working distances for 30 young adults (11 emmetropic, 17 myopic, and 2 hyperopic). Accommodative response was determined with a Canon R-1 infrared optometer under binocular viewing conditions, phoria was determined by the alternating cover test with prism neutralization, and fixation disparity was measured with a Sheedy disparometer.

Results. We found that the optimal powers of near addition lenses for the young adult subjects associated with zero retinal defocus were +0.92 D, +1.04 D, and +1.28 D at three viewing distances, 50 cm, 40 cm, and 30 cm, respectively. The optimal powers associated with −3 prism diopters (Δ) near phoria were +0.58 D, +0.35 D, and +0.20 D at the three distances, 50 cm, 40 cm, and 30 cm, respectively. In addition, we found high correlations between the initial accommodative error and the optimal power of the near addition lenses and between the initial near phoria and the optimal power of the near addition lenses.

Conclusions. The results suggest that when the effects of near addition lenses on the accommodative and vergence systems are both considered, the optimal dioptric power of the near addition lens is in a range between +0.20 D and +1.28 D for the three viewing distances. Using progressive lenses to delay the progression of myopia may have promising results if each subject's prescription is customized based on establishing a balance between the accommodative and vergence systems. Formulas derived from this study provide a basis for such considerations.
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Key Words: accommodation, vergence, phoria, myopia, near addition lenses

Numerous clinicians and researchers have used bifocal lenses[1–4] and progressive addition lenses[5–8] in an attempt to control or reduce the rate of myopia progression in children. The main hypothesis in these studies was that plus addition lenses could provide clear vision with less accommodation during near viewing, thereby slowing the progression of myopia.[7,8] However, none of these studies have reported the subjects' accommodative performance as they wore the addition lenses.

The effect of plus near addition lenses on the accommodative response has attracted the interest of several researchers.[9,10] Rosenfield and Carrel[9] compared 28 young adults' binocular accommodative responses while they viewed a 40 cm target through their distance correction alone or through their distance correction combined with one of +0.75 D, +1.50 D, +2.00 D, or +2.50 D addition lenses. They found that the lens power used to reduce the accommodative error to zero was correlated with the initial accommodative response error ($r = -0.72$, $p = 0.0001$). Therefore, uniformly prescribing one-power near addition lenses may not result in a reduction of the lag of accommodation for all subjects. Shapiro et al.[10] found that subjects' dioptric values, which was the combination of the accommodative response of the eye and the effective power of the addition lens, exceeded the accommodative demand (+3.00 D) by approximately 0.90 D and 1.12 D when tested binocularly through +2 D or +3 D lenses, respectively. In our previous study,[11] we measured 14 subjects' (7 emmetropic and 7 myopic) accommodative responses and near phorias when they were viewing a near target (40 cm) through +2 D addition lenses. This study found that when the subject was viewing through +2 D near addition lenses, the binocular dioptric value (i.e., the accom-

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modative response plus the effective power of the near addition lens) was greater than the stimulus for 12 of the 14 subjects. At the same time, the subject's near phoria shifted toward the exophoric direction by about 5.82 prism diopters (Δ), which was out of the normal range for the general population.[12]

Previous studies[9–11] have suggested that a +2 D addition lens is not the most appropriate means of producing zero accommodative error for most subjects. To be effective for different subjects, the power of the addition lens should be optimized based on the subject's accommodative error as well as the near phoria. This study was designed to determine the optimal dioptric value of near addition lenses, which would cause the least errors in the accommodative and vergence responses.

METHODS

Thirty young adults (average age of 26.2 ± 2.9 years) participated in this study. Among the 30 subjects, 11 were emmetropic (OD: −0.14 ± 0.20 D, OS: −0.24 ± 0.23 D), 17 were myopic (OD: −3.05 ± 1.47 D, OS: −3.04 ± 1.29 D), and 2 were hyperopic (OD: +1.13 ± 0.88 D, OS: +1.50 ± 1.06 D); 20 were females and 10 were males. Informed consent was obtained from each subject after the nature and possible consequences of the study were explained. The research followed the tenets of the Declaration of Helsinki and was approved by the Nova Southeastern University's Committee for the Protection of Human Subjects. All subjects' refractive error was corrected to 20/20 visual acuity or better. No subject had strabismus, accommodative dysfunction, vergence dysfunction, or ocular pathology, as determined by a comprehensive eye examination from the Eye Institute of Nova Southeastern University. The exclusion criteria for accommodative and vergence dysfunction was based on Morgan norms.[12] Subjects with an astigmatic refractive error >1.00 D were excluded. During the experiment, the refractive error of each myopic subject was corrected with contact or spectacle lenses based on the examination result in this study.

We measured accommodative response, phoria, and fixation disparity through multiple addition lenses (0.00 D, +0.50 D, +1.00 D, +1.50 D, and +2.00 D) at three working distances (33 cm, 40 cm, and 50 cm). The order of the three working distances and the order of the three measurements (i.e., accommodative response, phoria, and fixation disparity) conducted were randomized. The five near addition lenses followed the order from high to low to avoid near adaptation effect. The accommodative target was a color cartoon slide (24 × 35 mm^2), in which there was a picture of a young girl drawn with thin lines, mounted in front of a tungsten illuminator. The luminance of the target was 250 cd/m^2. The target was aligned with the subject's right eye under binocular viewing conditions and the accommodative response of this eye was measured by a Canon R-1 optometer. The addition lenses were inserted in lens wells mounted on the forehead rest of the Canon R-1 at a vertex distance of 12 mm from the subject's eyes. Each accommodative response value was calculated as the average spherical equivalent power (i.e., sphere power + 1/2 cylinder power) from at least 10 Canon R-1 readings. Because the Canon R-1 was designed to provide the power needed for spectacle correction, we converted all readings to the power at the subject's corneal plane.

Near phorias were determined by the alternating cover test with prism neutralization. In a previous study,[11] we have verified that there is no significant difference in near phoria measurements, obtained by three different methods, Maddox rod, cover test, and the von Graefe technique. Therefore, in this study, we used only the cover test to measure the subject's near phorias utilizing a single 1.6 M letter as a target at 33, 40, and 50 cm, respectively, under normal room illumination (450 lux). A prism bar (Gulden Oph-

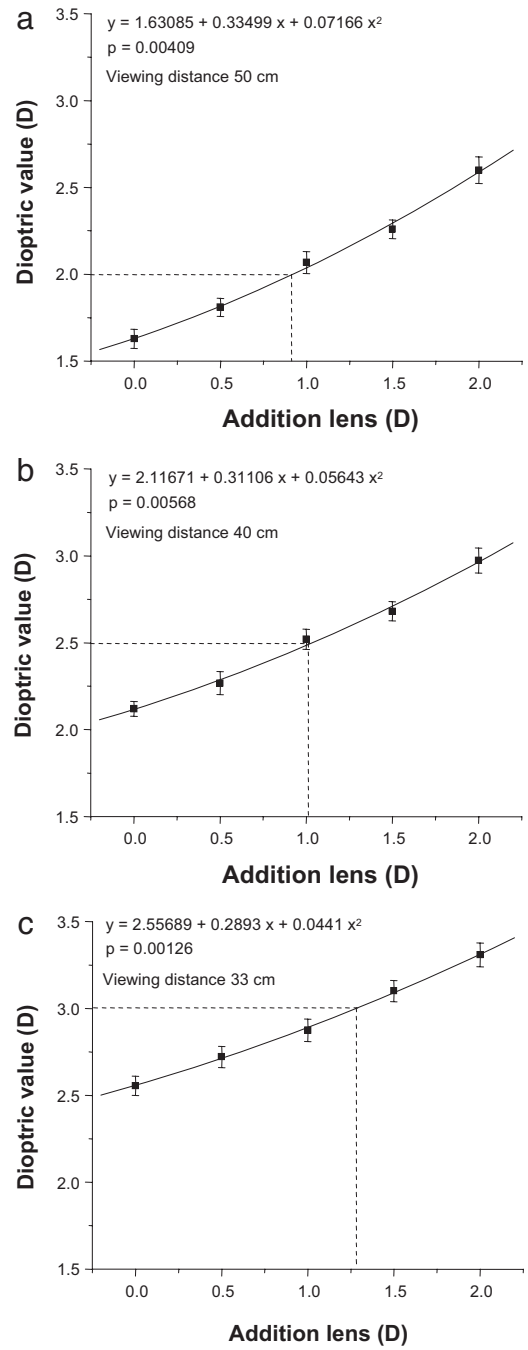

FIGURE 1.
The dioptric values are plotted as a function of the powers of near addition lenses for viewing distance, 50 cm (a), 40 cm (b), and 33 cm (c), respectively. Each point is the average of 30 subject's data. A regression curve is used to fit these data points in each plot. The optimal powers of near addition lenses are determined when the dioptric values are equal to +2.0 D, +2.5 D, and +3.0 D for the three viewing distances, respectively. Error bars are ±1 SE.

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thalmics, Model Berens B16, Lot: 9629) was used for this test. Using standard optometric technique, the examiner quantified the deviation with the alternating cover test with prism neutralization. The results were bracketed to achieve the endpoint and determine the magnitude of the deviation. For the three viewing distances, near phoria measurements were taken with the five near addition lens conditions.

Fixation disparity was measured with a Sheedy Disparometer, which has been described in detail in the optometric literature.[13,14] In this test, the subject was seated at eye level with the Sheedy Disparometer, which was fitted on a near point rod of a standard phoropter. A flashlight was used for illumination of the Disparometer. The subject was instructed to keep the letters around the testing window clear so as to ensure he/she fixated at the plane of the Disparometer. Each measurement was started with the subject stating that the two lines were not aligned, and ended when the two lines appeared aligned when the experimenter rotated a knob on the back of the Disparometer. Each data point was an average of three measures. For the three viewing distances, fixation disparity measures were taken with the five near addition lens conditions.

It was previously demonstrated[11] that there was no significant difference in accommodative response and near phoria between emmetropic and myopic subjects. In this study, we averaged the measured results across all 30 subjects in each condition. The two hyperopic subjects' data were in the range of average ±1 SD for each experimental condition; therefore, their data were included in the results. The data were fitted with regression curves to determine the optimal add powers associated with a zero accommodative response error and 3 Δ exophoria (i.e., the mid-point of Morgan norm).[12]

TABLE 1.
The optimal powers of near addition lenses for the three viewing distances: 50 cm, 40 cm, and 30 cm, which are obtained from the results in Figs. 1 and 3

Viewing distance (cm)	Add power associated with −3 Δ phoria	Add power associated with zero accommodative error
50	+0.58 D	+0.92 D
40	+0.35 D	+1.04 D
33	+0.20 D	+1.28 D

The data are obtained from the curve fitting results in Figs. 1 and 3.

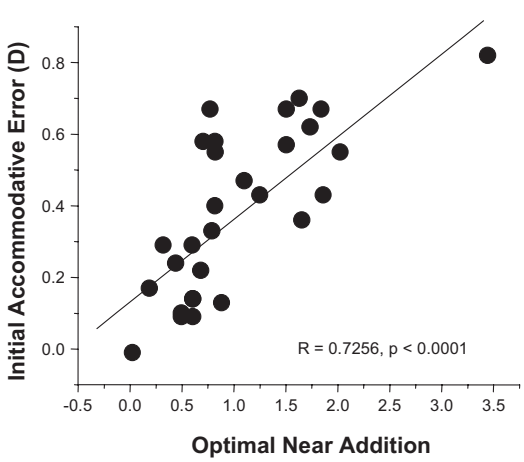

FIGURE 2.
The correlation between individual's initial accommodative error and the optimal near addition power for the 40 cm viewing distance.

RESULTS

The Canon R-1 optometer only reported the accommodative output without discriminating whether the response came from

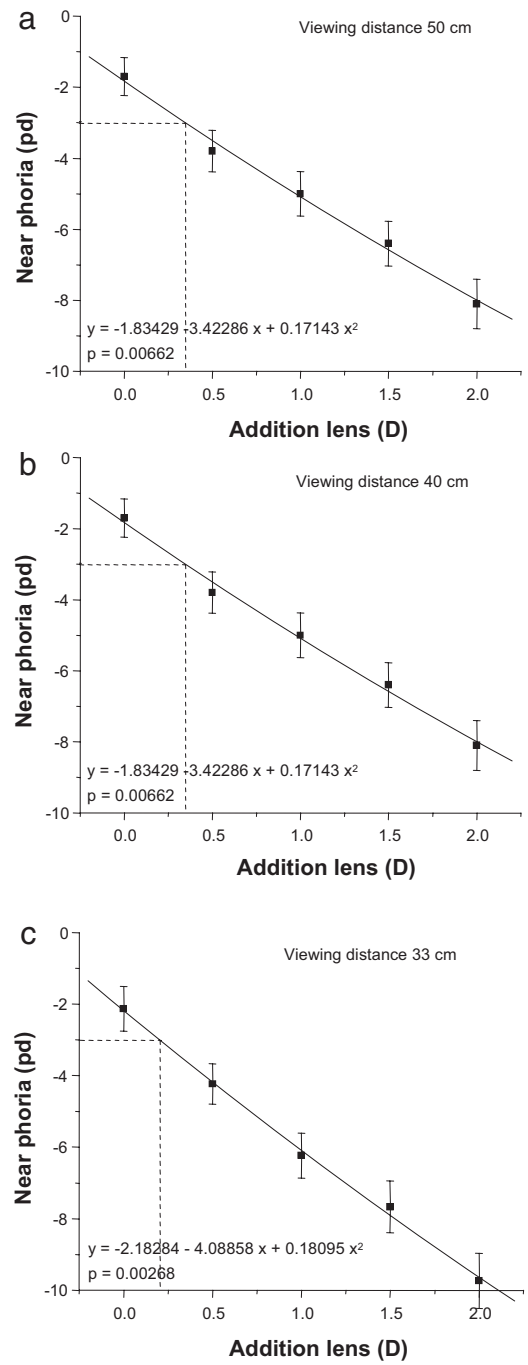

FIGURE 3.
The near phorias are plotted as a function of the powers of near addition lenses for viewing distance, 50 cm (a), 40 cm (b), and 33 cm (c), respectively. Each point is the average of 30 subject's data. A regression curve is used to fit these data points in each plot. The optimal powers of near addition lenses are determined when the near phoria is equal to −3 Δ for the three viewing distances, respectively. Error bars are ±1 SE.

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the eye alone or a combination of the eye's accommodative response and the power of the addition lens. For the purpose of this paper, we use the term "dioptric value" to represent the combination of the accommodative response of the eye and the effective power of the addition lens. For example, if a subject views the target at 40 cm through a +1.00 D addition lens and the Canon R-1 optometer reads −2.45 D, first we convert this reading to the corneal plane, which is −2.37 D (the vertex distance is 14 mm); then find the dioptric value is +2.37 D. The dioptric value is equal to the sum of the effective power of addition lens (+1.01 D) and the accommodative response of the eye (+1.36 D) at the corneal plane. The dioptric value evaluates the amount of retinal defocus when the eye views a target through the addition lenses. The averages of dioptric value were plotted as a function of the power of the addition lenses for three viewing distances, respectively, and are presented in Fig. 1 (a to c). For each viewing distance, the data were fitted with a regression curve. The optimal add powers were estimated from the regression curves based on the idea that the add power should not create any retinal defocus at that viewing distance (i.e., the dioptric value is equal to the accommodative demand). These optimal powers are listed in Table 1.

In order to investigate the relationship between the initial accommodative error and the optimal power value of the near add, we plotted the measured dioptric value as a function of the power of addition lenses for each subject under the condition of a 40 cm viewing distance. Then the data were fitted with a regression curve to find out the individual optimal power of the addition lenses, as we did for the average data. The accommodative error AE is equal to the difference between the accommodative stimulus (AS) and the accommodative response (AR).[15,16] In our tests, the AS is equal to 2.5 D and the AR is the individual accommodative response to the target at 40 cm measured with no addition lenses. The AE (=AS − AR) is named as the initial accommodative error. Fig. 2 shows the correlation between the initial accommodative error and the optimal power of the addition lenses based on our measurements ($r = 0.726$, $p < 0.0001$). The linear regression result is shown in following question:

$$AE = 0.134 + 0.238 \times (\text{Optimal power of the near add}) \quad (l)$$

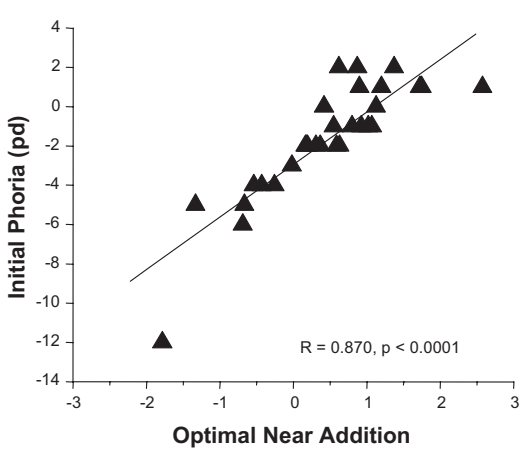

FIGURE 4.
The correlation between the individual's initial phoria and the optimal near addition power for the 40 cm viewing distance.

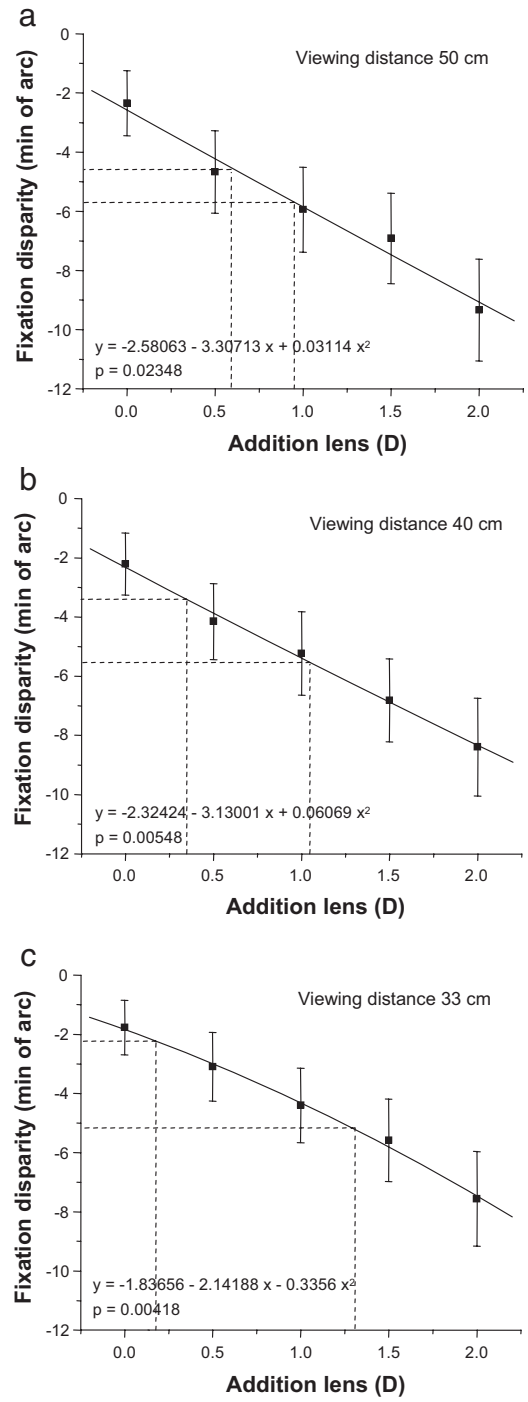

FIGURE 5.
The fixation disparity values are plotted as a function of the powers of near addition lenses for viewing distance, 50 cm (a), 40 cm (b), and 33 cm (c), respectively. Each point is the average of 30 subject's data. A regression curve is used to fit these data points in each plot. The possible ranges of fixation disparity are determined when the powers of near addition lenses are equal to the two optimal values obtained from Figs. 1 and 3 for each viewing distance. We found fixation disparities ranging from −4.5 Δ to −5.6 Δ for the 50 cm viewing distance, from −3.4 Δ to −5.5 Δ for the 40 cm viewing distance, and from −2.3 Δ to −5.13 Δ for the 33 cm viewing distance. These ranges are indicated with the dashed lines in each plot. Error bars are ±1 SE.

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The averages of near phoria were also plotted as a function of the power of addition lenses for three viewing distances, respectively. For each viewing distance, the data were fitted with a regression curve as presented in Fig. 3 (a to c). The optimal add powers to give the average subjects a near phoria of $-3\ \Delta$ were estimated from the regression curves. These optimal powers are listed in Table 1.

In order to investigate the relationship between the initial phoria and the optimal power value of the near add, we plotted the phoria measurements as a function of the power of the addition lenses for each subject with a 40 cm viewing distance. Then the data were fitted with a regression curve to find out the individual optimal power of the addition lenses, as we did for the average data. The individual initial phoria was obtained from the data when the cover test was conducted under no addition lenses condition. Fig. 4 gives the correlation between the initial phoria and the optimal power of the addition lenses based on our measurements ($r = 0.870$, $p < 0.0001$). The linear regression result is shown in following equation:

$$\text{Initial phoria} = -2.959 + 2.770 \times (\text{Optimal power of the near add}) \quad (2)$$

The criterion of zero accommodative response provides a condition at which the retinal blur is minimized. The criterion of $-3\ \Delta$ near phoria comes from the mid-point of Morgan norm.[12] We believe that the $-3\ \Delta$ is better than zero Δ as the ideal level of near phoria. If the subject is orthophoric at near, his vergence accommodation will be zero when he views a near target binocularly. However, in a $-3\ \Delta$ situation, the subject will have a certain amount of vergence accommodation to help the accommodative response when he views a near target.

The averages of fixation disparity were plotted as a function of the power of addition lenses for three viewing distances, respectively. For each viewing distance, the data were fitted with a regression curve [Fig. 5 (a to c)]. From the results of the optimal add powers estimated from dioptric values and near phorias, we found that these add powers might cause the subjects to have fixation disparities ranging between -2.28 and -5.60 min of arc as indicated in Fig. 5. For a normal oculomotor system, the fixation disparity is expected to be approximately within ± 5 to ± 6 min of arc.[17,18] Therefore, the optimal addition powers estimated with the above methods would not significantly affect binocular fixation. However, if $+2$ D addition lenses were used, the average fixation disparities would be -9.07, -8.34, and -7.46 min of arc for viewing distance 50, 40, and 33 cm, respectively. Therefore, the $+2$ D addition lenses may create a conflicting condition, in which the accommodative demand is reduced, but the fixation disparity becomes larger, which could potentially result in eye strain.[1]

DISCUSSION

In this study, we measured the changes in accommodative responses, phoria, and fixation disparity when the subject viewed the target at three distances and through five different addition lens powers. We used the criterion of zero accommodative error to find the optimal add power related to the accommodative measurements for each viewing distance. For the phoria measurements, the criterion of $-3\ \Delta$ was used to determine the optimal add powers. From Table 1, we find that when the viewing distance moves closer to the subject, the optimal add power has to be decreased if we want to keep the phoria at the $-3\ \Delta$ level. However, if we want to maintain the accommodative error at zero, the optimal add power has to be increased. This antipathetic relationship reveals the interaction between the accommodative and vergence systems. The result of this study suggests that if one wants to use plus addition lenses to decrease the load on the accommodative system for near visual tasks, one has to consider that the lenses may increase the load on the vergence system.

Our results are consistent with the results from previous clinical reports[19] and theoretical research work.[20] When the viewing distance is at 40 cm, we estimated that the optimal power for addition lenses was in the range of $+0.35$ D to $+1.04$ D. Birnbaum[19] summarized the results of clinical research on control of myopia progression and suggested that low-power addition lenses ($+0.75$ to $+1.25$ D) were most effective in slowing myopia progression in myopes, who demonstrated esophoria at near, low positive relative accommodation, and greater plus acceptance on the binocular cross-cylinder test. Hung and Ciuffreda[20] developed a comprehensive model of refractive error development based on a dual-interactive feedback model of accommodation and vergence. Using this model they were able to predict the optimal power of addition lenses based on individual parameters of the oculomotor system. The theoretical results supported the idea that low-power addition lenses might reduce the retinal defocus and result in a balance of the interactive accommodative and vergence components.

Rosenfield and Carrel[9] estimated the optimal powers of near addition lenses based on the accuracy of the accommodative response and found that the addition powers should be -1.08 D, $+0.78$ D, and $+2.18$ D if the initial lead or lag of accommodation were -0.30 D, $+0.30$ D, and $+0.78$ D, respectively (here, the minus sign represents the lead of accommodation and plus sign represents the lag of accommodation). Based on the relationship between the initial accommodative error and the optimal power of the near addition lens derived from this study (Eq. 1), if we use the same values (i.e., -0.30 D, $+0.30$ D, and $+0.78$ D) as the initial accommodative errors as used in the Rosenfield and Carrel study to compute the optimal powers, the results are -1.82 D, $+0.70$ D, and $+2.71$ D, respectively. The difference in results between the Rosenfield and Carrel study and this study can be attributed to the different samples of subjects. However, we need to mention that the optimal powers of near addition lenses cannot be determined based on the accommodative response alone.

Based on this study, we have shown that in the prescription of a near addition, not only the subject's accommodative error, but also the phoria and fixation disparity have to be taken into account also, i.e., the balance between the accommodative and vergence systems is important. There are two rationales in prescribing near addition lenses to prevent myopic progression. Some clinicians and researchers, who conducted trial studies using bifocal lenses and progressive addition lenses, hypothesized that the plus addition lenses could reduce the accommodative demand and as a consequence slow the rate of myopic progression.[5–8] However, recent research evidence suggests that the development of myopia may be caused by blurred image on the retina.[16,21–24] The Eq. 1 derived in this study provides an estimation of the optimal power of near addition lenses based on the subject's initial accommodative error. However, Eq. 2 is equally important. This formula provides the

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optimal power of near addition lenses based on the subject's initial phoria. It indicates that higher optimal power of near addition lenses is only suitable for those subjects who have a larger lag of accommodation accompanied by a higher near esophoria. For most subjects, the optimal power of near addition lenses is a compromise between the status in accommodative error and near phoria. Our data in Table 1 are from the averages of 30 subjects who participated in this study. For an individual situation, the optimal power can be determined using the Eqs. 1, and 2 based on the individual's initial accommodative error and near phoria. For example, if a subject has +0.42 D initial accommodative error (i.e., the lag of accommodation) and +0.365 Δ near esophoria when he views a near target at 40 cm, he can be given +1.20 D near adds based on each of the two formulas. There is no discrepancy in this case. If another subject has +0.42 D initial accommodative error and −2.00 Δ near exophoria, then the results calculated from the two formulas are different: +1.20 D is the best power for reducing the accommodative error, +0.35 D is the best power for reducing the near phoria and fixation disparity. In this case, we do not know which value is better for the subject. But, we do know that the near adds have to be in this range (i.e., +0.35 D to +1.20 D) and the +2.00 D adds is probably too high in most time.

Using progressive lenses to delay the progression of myopia may have promising results if each subject's prescription is customized. The Eqs. 1, and 2 derived from this study provide a basic idea for such considerations. Because plus addition lenses alter the interaction between the accommodative and vergence components in a more complicated manner than simply changing retinal focus or accommodative posture, the long-term effect of near addition lenses on the subject's accommodative and vergence performance should be considered in next study. In addition, since our subjects were young adults, we cannot say the results of this study apply directly to children. A similar study with children would be a good avenue for further research.

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