Accommodative Responses under Binocular Conditions with Various Amounts of Plus Add

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ABSTRACT
Background: The purpose of this paper is to provide data on the binocular accommodative response (AR) as accommodative stimulus (AS) is changed with plus adds. This may be helpful in refining guidelines for prescribing nearpoint plus adds.

Methods: AR was measured with a Canon Autoref R-1 autorefractor on 50 subjects, 20 to 30 years of age. Letters were viewed at 40 cm through adds of 0 to +2.50D (0.25D steps) presented in random order. Linear regression of AR on AS was performed to determine slope, y-intercept, add at which AR equaled AS, and add at which AR was 0.25D less than AS for each subject.

Results: The mean lag of accommodation (AS-AR) at the 2.50D stimulus level was 0.33D (SD=0.36). The mean slope was 0.51D/D (SD=0.16). The mean add at which AR equaled AS, and add at which AR was 0.25D less than AS for each subject.

Conclusions: Accommodative response decreased as plus lenses were added, the decrease being about 51% on average. Because of the wide inter-subject variability in accommodative parameters, lens powers for optimal nearpoint performance will vary from one individual to another.

Key words: accommodative response, accommodative stimulus, bifocals, dynamic retinoscopy, myopia, ocular accommodation.

The prescription of nearpoint plus adds can have beneficial effects on nearpoint comfort and performance for many non-presbyopic patients. One indication for nearpoint plus is a high lag of accommodation. Most individuals have a small lag of accommodation for near point objects, averaging between approximately 0.25 to 0.75D for objects at 40 cm.1-7

Using dynamic retinoscopy, Haynes8,9 observed that there are different response patterns in the change of accommodative response (AR) with changing accommodative stimulus (AS). Because of these varying response patterns of AR as AS is changed with lenses, two patients with the same lag of accommodation through their distance subjective refraction may have different ARs with the same plus lens add. One can then ask whether they would benefit most from different add powers even though their lags of accommodation through no add were the same. A better understanding of the change in AR with changes in AS through plus adds may be helpful in refining methods for prescribing nearpoint plus adds for improved nearpoint performance.

With the use of an x,y coordinate plot of AS on the x-axis and AR on the y-axis, slopes and y-intercepts can be calculated to describe the relationship of AR and AS for a given individual. In most studies in the literature a lag of accommodation is present for accommodative stimuli of about 1D or more, and slopes are usually less than 1D/D.10-12 Slopes less than 1D/D indicate that 1D change in AS results in less than 1D change in AR. Laboratory studies on accommodative response have often used changes in distance or a Badal system to vary accommodative stimulus rather than plus adds. They also used a range of accommodative stimuli wider than would be present with typical nearpoint reading distances and typical nearpoint plus adds, or have used monocular rather than binocular viewing. Changes in binocular AR with changes in AS with common plus adds for a standard nearpoint viewing distance surprisingly do not seem to have been studied extensively.

An understanding of inter-subject variation in accommodative response changes with plus adds may be helpful in the further development of theory of dynamic retinoscopy. This paper provides data on the binocular AR as AS is changed with varying powers of added plus lens, including low adds that would be commonly used in clinical practice.

METHODS
Data were collected on a population of 50 optometry students between 20 to 30 years of age. Subjects were recruited on a volunteer basis through school email. To be considered for this study, subjects had to be correctable to at least 20/20 distance visual acuity in each eye. Exclusion criteria included any self-reported eye disease or any strabismus as determined by cover test.

Baseline information about each subject was determined first. The cover test was performed at distance and near to determine if strabismus was present. A subjective refraction, including Jackson cross cylinder astigmatism testing and prism

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dissociation balance, was performed with an endpoint of maximum plus to best visual acuity (BVA). An over-refraction was performed on subjects wearing contact lenses or glasses. The findings from the refraction were presented over the subject’s habitual prescription using Janelli clips. The spherical equivalent was used for subjects with residual cylinder of less than 0.50D.

Accommodative response (AR) was measured through the BVA and plus adds in 0.25D steps from 0 to 2.50D. The accommodative stimulus (AS) levels of 0, 0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00, 2.25, 2.50D correspond to plus adds of +2.50, +2.25, +2.00, +1.75, +1.50, +1.25, +1.00, +0.75, +0.50, +0.25D, and 0, respectively. The Canon Autorefr R-1 was used to take the AR measurements. The open-view design of this autorefractor allowed the subject to read a paragraph of 20/60 letter size 40 cm away while the measurements were taken. The lens powers were presented over both eyes, and subjects viewed the fixation target binocularly. Measurements were taken from the right eye only. The order for lens presentation was determined by randomly pulling a number correlating to the lens power from an envelope. The number 0 referred to the BVA, 1 to +0.25 over the BVA, 2 to +0.50 over the BVA, etc. The first number drawn indicated the first presented and then other numbers were successively until all lens options had been exhausted. The subjects were instructed to read the paragraph to themselves while the machine was being aligned. Once measurements began, the subject was instructed to fixate on one word and move to the next word after each subsequent measurement.

Five valid measurements were taken for the BVA and for each lens power. The spherical equivalent of each measurement was calculated, and the average for each lens power was found. Invalid measurements were discarded based on the following criteria: (1) Error readings displayed on the autorefractor as “ERR”. (2) Any readings with cylinder greater than 1.00 D. Because the subjects wore lens corrections for their ametropia, including astigmatism, large cylinder values should not have been present. (3) Any readings where the sphere differed by more than 1.00D from the previous reading. (4) Any initial reading where the sphere differed by more than 1.00D from the next two readings.

Before data collection began, the calibration of the Canon autorefractor used in the study was checked by comparing the distance refraction results it obtained to the subjective refraction for one eye of an absolute presbyope. The spherical equivalent of the subjective refraction was -3.12D. The mean spherical equivalent of ten Canon readings on that eye was -3.19D, with a standard deviation of 0.24D.

A total of 55 subjects were initially recruited for the study. Data were not obtained for five subjects due to multiple invalid readings from the autorefractor, leaving a study sample of 50 subjects. The AS and AR were determined based on the following equations:

\[ AS = 2.50 - \text{mean autorefractor reading} \]

\[ AR = \text{mean autorefractor reading} - \text{lens power} \]

For each subject, graphs were generated using the Kaleidagraph computer program, with accommodative stimulus on the x-axis and accommodative response on the y-axis. From these graphs, the program calculated slope and y-intercept by linear regression. The add power at which AR equaled AS was calculated from the slope and y-intercept. In addition, the add power at which AR was 0.25D less than the AS was calculated from the slope and y-intercept.

**RESULTS**

Some examples of the x,y plots of AS and AR are shown in Figure 1. Mean accommodative responses are shown in Table 1. The mean AR at the 2.50D AS was 2.17D (SD=0.36), indicating a mean lag of accommodation of 0.33D. Five persons had leads of accommodation, with the highest lead being 0.48D. The highest lag of accommodation was 1.55D. A frequency distribution of lags is shown in Figure 2.

The lowest slope was 0.11 diopters of AR per diopter of AS, although that low a slope was unusual. The second lowest slope was 0.26D/D. The highest slope was 0.80D/D. The mean slope was 0.51D/D, with a standard deviation of 0.68D/D.
A frequency distribution of the slopes is shown in Figure 3. Slopes were less than 1D/D for all subjects, indicating that AR changes are less in magnitude than the corresponding AS changes. The mean y-intercept was 0.80D, with standard deviation of 0.47.

The mean add power at which AS and AR were equal was 0.88D, with a standard deviation of 0.66. The adds at which AR and AS were equal ranged from -0.67D for one of the subjects with a lead of accommodation to +2.50D for one of the subjects with a lag. For individual subjects, adds higher than the add power at which AR=AS would result in a lead of accommodation, and adds lower than the add power at which AR=AS would result in a lag of accommodation.

Because a small lag of accommodation is normal, the mean add powers needed to arrive at a difference in AS and AR approximately equal to a normal lag were also determined. The mean add needed to make AR 0.25D less than AS calculated from the regression line data was 0.29D (SD=0.71). A frequency distribution of the adds which made AR 0.25D less than AS is shown in Figure 4. The range was -1.38D for one of the subjects with a lead of accommodation to +1.87D for one of the subjects with a lag.

**DISCUSSION**

**Comparison of Results to Findings from Dynamic Retinoscopy**

In MEM retinoscopy the dioptric estimation of the motion of the reflex is a measure of the difference between AR and AS. In the present study, the average AR to a 2.50D AS was 2.17D. That would correspond to a 0.33 D lag of accommodation for a 40 cm object viewed through the subjective refraction. That amount of lag can be compared to the average values reported in the literature for MEM retinoscopy: 0.23D and 0.34D in two studies with children; 2,3 0.50D, 0.56D, and 0.74D in three studies with young adults; 4,13,14 and 0.35D in a study of patients with a wide range of ages. 6

In low neutral dynamic retinoscopy, lenses are added until a neutral reflex is observed. At that point, AR and AS are equal. In the present study, the average add at which AS and the interpolated AR were equal was +0.88D. This can be compared to average low neutral dynamic retinoscopy findings of +0.50D, +0.61D, and +0.88D in three studies in young adults. 4,14,15

The AR/AS slopes in this study can also be compared to findings using dynamic retinoscopy. Haynes8,9 described a dynamic retinoscopy procedure he called MEM-LN because it combined aspects of both MEM and low neutral retinoscopy. MEM dynamic retinoscopy was performed through the subjective refraction and then through increasing amounts of plus add. One study using the Haynes MEM-LN procedure on a sample of 20 young adults found a mean slope of 0.49D/D (SD=0.17). 14 Those results were very close to the mean slope of 0.51D and the standard deviation of 0.16D in the present study. Slopes could also be
derived from Tassinari’s MEM-twice procedure. Tassinari performed MEM with the distance subjective refraction lenses in place and again with plus lenses based on the binocular cross cylinder test. He reported that for 211 patients, the mean change in accommodation was 62% of the added plus power. That is a little greater than the 51% implied from the slope in the present study.

**Implications for Comparisons of MEM and Low Neutral Dynamic Retinoscopy**

The results of this study have implications for the clinical application of dynamic retinoscopy. The lower the slope of the AR/AS function, the closer the lag of accommodation at 2.50D stimulus will be to the amount of plus added to make AS and AR equal. Therefore, MEM and low neutral findings will be closer when the slope is low and farther apart when the slope is high. One can be illustrated with two examples with testing at 40 cm: Example 1. MEM with 2.50D stimulus showed a lag of 1.25D for an AR of 2.50 – 1.25 = 1.25D at that stimulus level. The low neutral finding was 1.50D, meaning the AS and AR were equal at 1.00D. The difference in accommodative responses on MEM and low neutral was 0.25D and the difference in stimulus was 1.50D for a slope of 0.17D/D. Example 2. MEM showed a lag of 0.25D at a stimulus of 2.50D, indicating a 2.25D response. The low neutral finding was +1.50D, indicating that AS and AR were equal at 1.00D. The difference in responses was 1.25D, and the difference in stimulus was 1.50D, for a slope of 0.83D/D.

**Implications for Prescription of Plus from Dynamic Retinoscopy**

Plus adds are often prescribed for patients with high lags of accommodation. The normal accommodative condition is a low amount of lag of accommodation for near objects. Clinical guidelines for prescription of plus add were from dynamic retinoscopy recommend prescribing less plus than the measured lag. Perhaps the most common guideline is to determine the add by subtracting 0.25D from the lag found with MEM. That guideline appears to have been published first by Greenspan. If we were to apply that guideline to the data from the present study, we could look at the distribution of lags at the 2.50D AS level (Figure 2), and subtract 0.25D from those lags. A plus add would not be recommended for the majority of subjects with that guideline and the highest plus add suggested would be +1.25D.

Birnbaum recommended prescribing the add that would make the with motion on MEM to be between 0.12 and 0.50D. In other words, the AS-AR difference would be 0.12 to 0.50D. Figure 4 shows a frequency distribution of adds that would make the AS-AR difference equal to 0.25D for the subjects in the present study. The most common plus adds with that guideline are +0.50 and +0.75D, with the highest add being +1.75D.

**Bimodal distribution of adds**

The distribution of adds that make the AR 0.25D less than the AS is bimodal with one peak at 0 and -0.25D and another peak at +0.75D. All of the 12 subjects at the 0 and -0.25D add levels had leads of accommodation or lags of accommodation through subjective refraction that were less than the mean lag. Of the 25 subjects at the +0.50D or higher D level, 20 had lags of accommodation higher than the mean lag. One could suggest that the two peaks could represent at least two different types of accommodative behavior, with those with the higher add powers being the ones who would benefit most from plus at near.

**Implications for Myopia Control**

One theory on the etiology of myopia suggests that retinal image clarity modulates ocular growth rates and axial elongation. A common method of myopia control that has had varying success over the years has been the use of bifocal and progressive addition lenses. If a critical level of retinal image defocus plays a role in initiating myopia progression, then knowing the relationship of AR and AS for a given patient may be helpful in finding the appropriate multifocal power for myopia control for that patient. Some investigators are developing models for the relationship of accommodation and vergence parameters to refractive change in order to make predictions of the best lens corrections for slowing myopia progression. Such models allow for different optimal lens corrections for different individuals. The wide variability of lags, slopes, adds in Figures 2-4 in the present study illustrate that there is wide individual variability in the add power needed for particular levels of the AS-AR relationship.

**SUMMARY AND CONCLUSIONS**

Lag of accommodation at an AS of 2.50D averaged 0.33D (SD=0.36). The slopes of AR on AS ranged from 0.11 to 0.80 diopter per diopter, with a mean of 0.51D/D (SD=0.16). The slopes indicate that the average decrease in accommodative response was 51% of the added plus lens power, but that it varied from 11 to 80%. The mean add at which AR equaled AS was +0.88D (SD=0.66). Plus adds greater than the add at which AR and AS were equal would result in a lead of accommodation for individual subjects. The add at which AR was 0.25 D less than AS averaged 0.29D (SD=0.71). Each of these accommodative parameters showed significant inter-subject variability, indicating that lens power for optimal nearpoint performance will vary from one individual to another.

**REFERENCES**


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