Changes in the convergence accommodation to convergence ratio with advancing age

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Changes in the convergence accommodation to convergence ratio with advancing age

Abstract
PURPOSE: This study was designed to investigate the reported decline in the CAIC ratio with aging, as well as the effects of near addition lenses on the CAIC as presbyopia progresses, using a clinical methodology.

METHOD: A cross-sectional evaluation of 93 subjects age 25 to 54 was conducted. Accommodative amplitudes and CAIC ratios were determined for each subject. CA/C ratios were determined using the CAnon R-1 infrared optometer and DOG target with prism placed before the non-measured eye.

RESULTS: The expected age-related decline in the CA/C was seen, beginning at approximately age 32 for subjects as a whole, and at approximately age 27 for those who wore nearpoint lenses. The age-related decline was more predictable for those who wore near addition lenses. There was a slight tendency toward higher CAIC ratios among subjects who did not wear near addition lenses. When the CA/C was analyzed by accommodative amplitude instead of age, significant differences (p<0.05) were found, showing higher CA/C ratios for subjects who did not wear adds.

CONCLUSION: This study presents further evidence of an age-related decline in the CA/C ratio. The rate of decline in the CAIC ratio may be related to the use of near addition lenses.

Degree Type
Thesis

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CHANGES IN THE CONVERGENCE ACCOMMODATION TO CONVERGENCE RATIO WITH ADVANCING AGE

By

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B.J. FISKE

A thesis submitted to the faculty of the
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Pacific University
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Adviser:

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Marsha Beach was born in Cortez, Colorado. She graduated from Grand Junction High School in 1969. She graduated magna cum laude from Mesa State College in Grand Junction, CO, in 1988. She has two daughters, Deanna, and Kara.

Marsha's interests include the performing arts, enjoying attending concerts and the theatre, and the study of other cultures, such as Native American.

Marsha was awarded a scholarship from the Forest Grove Lion's Club. She is a member of the BSK Honor Fraternity. She participated in an optometric mission with the Amigo's Club to the city of Merida in Mexico. Marsha plans to seek employment upon graduation from Pacific University.

B.J. Fiske was born in Worcester, Massachusetts. She graduated from Brainerd High School in Chattanooga, Tennessee in 1969. She graduated from the University of Tennessee at Chattanooga with a B.A. degree in Human Services in 1974. She graduated from Oregon Institute of Technology in Klamath Falls, OR, in 1979 with an A.A.S. in Dental Hygiene. She was employed in private practice dentistry for a number of years. She attended Southern Oregon State College in Ashland, Oregon to complete pre-optometry requirements.

Her interests include playing the guitar, flute, and recorder. She enjoys attending concerts and the theatre.

B.J. plans to eventually own an optometry practice.
Abstract
PURPOSE: This study was designed to investigate the reported decline in the CA/C ratio with aging, as well as the effects of near addition lenses on the CA/C as presbyopia progresses, using a clinical methodology. METHOD: A cross-sectional evaluation of 93 subjects age 25 to 54 was conducted. Accommodative amplitudes and CA/C ratios were determined for each subject. CA/C ratios were determined using the CAnon R-1 infrared optometer and DOG target with prism placed before the non-measured eye. RESULTS: The expected age-related decline in the CA/C was seen, beginning at approximately age 32 for subjects as a whole, and at approximately age 27 for those who wore nearpoint lenses. The age-related decline was more predictable for those who wore near addition lenses. There was a slight tendency toward higher CA/C ratios among subjects who did not wear near addition lenses. When the CA/C was analyzed by accommodative amplitude instead of age, significant differences (p<0.05) were found, showing higher CA/C ratios for subjects who did not wear adds. CONCLUSION: This study presents further evidence of an age-related decline in the CA/C ratio. The rate of decline in the CA/C ratio may be related to the use of near addition lenses.
Acknowledgements

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Changes in the Convergence Accommodation to Convergence Ratio With Advancing Age

Marsha J. Beach, B.S.
Bonnie J. Fiske, B.A., A.A.S.
Bradley Coffey, O.D., F.A.A.O.

Introduction
Everyone who lives long enough eventually develops presbyopia, disrupting clear and comfortable near vision. Presbyopia is defined as a reduction of accommodative ability occurring normally with age and necessitating a plus lens addition for satisfactory visual acuity at near, sometimes quantitatively identified by the recession of the near point of accommodation beyond 20 cm.1

Everyone over 50 years of age is affected by a loss of accommodative amplitude. Presbyopia is so universally experienced it is considered one of the most reliable biomarkers of human age known.2 The age when loss of accommodation becomes clinically significant is generally between the ages of 38 and 45, and is approximately complete by age 55.3

Numerous researchers have attempted to explain the mechanism of presbyopia, but there is no clear consensus as to the exact mechanism(s) involved.2,4 Proposed mechanisms are loss of lens elasticity,5 loss of elasticity of the choroid,2 decreased ciliary body strength6 or mobility,7 changes in lens curvature,8 changes in the lens capsule,6 altered zonulo-lenticular geometry,9 and changes in the vitreous body.10 The etiology is most likely multifactorial,4 with all the components of accommodation affected by the aging process.2

Optometric practitioners are very familiar with the presentation and treatment of presbyopia, many of us on a very personal level. But we know relatively little about convergence and accommodation interactions during and after the onset of presbyopia. The relationship between convergence and accommodation in
Pre-presbyopes is well documented in optometric literature. Convergence accommodation is defined as accommodation changes induced by, or associated with, changes in convergence. The present researchers wondered whether there are any significant changes in the convergence accommodation to convergence (CA/C) ratio with increasing age, specifically with the onset and development of presbyopia.

According to Schor's model of the mutual interaction of accommodative and convergence motor systems, convergence and accommodation responses are regulated by negative feedback loops. Both accommodation and convergence are controlled by closed loop conditions under normal circumstances, with each having a cross link to the other system, resulting in convergence accommodation when the eyes converge, and accommodative convergence when the eyes accommodate. These cross links are known as the CA/C and AC/A ratios. Schor has demonstrated these ratios are somewhat plastic, and can increase or decrease with changing demands on the visual system. That is to say, tonic adaptation of accommodation and of vergence can change the set-points from which the quicker phasic response systems operate. For instance, a high CA/C ratio is associated with a high adaptation of tonic accommodation and a low adaptation of tonic vergence. The converse is true for a low CA/C. The function of the cross links is to coordinate the motor responses of accommodation and vergence under open loop conditions, when there is a large amount of blur or disparity.

It has been determined that CA/C ratios can be reliably measured by measuring the change in accommodation when prism is interjected under open accommodative loop conditions. A method that has been found to be successful in opening the accommodative loop is the use of a Difference of Gaussian (DOG) target. The DOG target provides an adequate stimulus to sensory fusion without stimulating
reflex accommodation. It has been shown that the CA/C ratio declines steadily with age, from childhood to middle age, but little research has been done that measures the CA/C as presbyopia becomes complete. Tsuetaki and Schor stated "clinical norms for...CA/C ratios still need to be determined on a large population."  

This study evaluates changes in the CA/C ratio with advancing age, using a clinical methodology. The use of near lens additions was examined as a variable that could potentially have an effect on accommodative amplitude or on CA/C ratios. It is widely accepted among optometric practitioners that accommodative exercises can increase accommodative facility and amplitude. But is the reverse true, that if accommodation is under-utilized, it could result in lowered accommodative amplitude? If use of nearpoint lenses in pre-presbyopes could result in relaxation of tonic accommodation, it could potentially result in a lower CA/C ratio.

Methods

Subjects

Subjects were between the age of 25 and 54, and were recruited from Pacific University students, faculty, administrators, and staff. A few subjects were recruited from the general public. Ninety-three subjects, 34 men and 59 women, were accepted. The number of subjects by half decade was approximately evenly distributed, with ten to twenty-two subjects per half decade. The largest group was the 30 to 34 year olds, and the smallest was the 50-54 year old group. All age groups contained spectacle add wearers and non-add wearers. See Table 1 for exact group numbers.

---------Insert Table 1 about here----------
Subjects were required to demonstrate stereo acuity of 40 sec arc, and habitual visual acuities of at least 20/30 Snellen OD, OS, and OU at 6 m and at 40 cm.

Subjects were excluded if they had strabismus, amblyopia, a history of strabismus surgery, any injuries to the eyes or ocular muscles, cataract, nervous system disorders that could affect vision or eye movements, or glaucoma. Other exclusions were the use of any medication that could affect pupil size, accommodative ability, or ocular muscle function, including street drugs and alcohol. Subjects were excluded if they could not achieve sensory fusion with the prisms used to measure the CA/C ratio.

Procedure
Screening Tests
Subjects were screened for suitability with a verbal questionnaire, followed by screening tests. Screening tests included distance visual acuity, using a projected target at 6m from an American Optical acuity chart with standard room lighting. All acuities were taken through the subjects' habitual distance and near lenses. Near acuities were taken using a reduced Snellen chart at 40 cm with standard room lighting and a 60 W near point light positioned 15 cm above the card in such a manner as to eliminate glare.

Stereo acuity was tested using the Wirt Rings included in the Randot Butterfly, manufactured by Stereo Optical Corporation, held at 40 cm with subjects wearing polarized glasses over their habitual lenses, if any.

Unilateral and alternate cover tests were performed, in that order, to rule out strabismus. First the distance cover tests were performed with an isolated 20/20 letter on the projected AO chart at 6 m. Then the near cover tests were performed using a fixation bead held at 40 cm as a target.
Accommodative amplitude was measured using the Donders Push Up method, using a 0.62 M paragraph target, held at 55 cm, then brought closer to the subject at a rate of 5 cm per second. Blur out and recovery, (when the material could first be read) OD, OS, and OU were recorded. Measurements were taken through the subjects' habitual distance lenses if possible. The distances were recorded in centimeters. If a subject could not clear the reading material through their distance lenses they were permitted to use their habitual near lenses. For these subjects, the blur out and recovery distances were converted into dioptric equivalents and the add power subtracted.

Lensometry was performed on all spectacles to determine the sphere and cylinder power, the cylinder axis location, and the add power, if applicable. These data were used to calculate the amount of prism induced by looking through the spectacle lens at a point other than the optical center during the CA/C measurements.

Subjects were asked the duration and percent of use of add power for near tasks. They were asked how frequently they removed their spectacles or contact lenses for near tasks. A subject was considered to be an add wearer if a near lens addition had been worn longer than four months and for at least 40% of all near tasks, or if a low myope removed their spectacles or contact lenses for near tasks.

Forced vergence fixation disparity curves were measured to determine first, whether subjects were able to fuse with the prism and second, how fully they responded to the prism used in the measurement of CA/C ratios. A three-point forced vergence fixation disparity curve was generated using the Sheedy Disparometer at 40 cm with a 60W bulb placed 20 cm from the device. The disparometer was held by the examiner in a normal reading position for the subjects. The subjects adjusted the angle to eliminate glare. Measurements were taken with base in (BI) prism interjected, no prism (Plano), and base out (BO) prism, in that order. Prisms were
held by the subject at the spectacle plane, before the left eye. Disparities were measured twice in each prism condition by bracketing, starting with an exo target disparity, then an eso target disparity. The prism used was 10Δ, unless the subject had difficulty fusing, in which case either 8Δ or 5Δ was used.

**Measurement of Changes in Accommodation**

Accommodative changes were measured using the Canon Autoref R-1 autorefractor. The target was a 0.2 cpd DOG target, shown in Fig. 2. The target was placed at 40 cm, directly in front of the right eye, requiring subjects to converge for a near target. Dim illumination was used, provided by a single 60 W bulb, directed at an eight foot ceiling, 1.5 meters from the autorefractor. Illumination on the target was 2 footcandles. Fig. 3 shows a schematic of the set-up.

Subjects were instructed to wear their habitual distance lenses, tilted slightly along a horizontal axis to reduce glare and to facilitate readings with the Canon R-1. They were instructed to look steadily at a small area at the center of the target, and to be sure to "keep it single, but not necessarily clear." All prisms were held by the subject at the spectacle plane before the left eye. The DOG target was placed directly in front of the right eye, thus vergence movements were performed by the left eye, keeping movement of the right eye to a minimum to facilitate accurate measurement of accommodation in the right eye.\textsuperscript{20} Readings were first taken with the base in prism, no prism, then with base out prism. Subjects were seated at the optometer, and the optometer adjusted and focused before the prism was placed before the eye. When the prism was interjected, readings were completed within 10 seconds, to keep prism adaptation to a minimum.\textsuperscript{12} Five readings were taken under each prism condition and averaged. These data were the changes in accommodation for the prism conditions.

**Calculation of the CA/C Ratio**
CA/C ratios were calculated by the following formula:
\[ \text{CA/C} = \frac{\Delta \text{Acc}}{\Delta \text{Conv}}, \]
where \( \Delta \text{Acc} \) = the change in accommodation measured by the autorefractor, and \( \Delta \text{Conv} \) = total change in prism power, BI to BO.

Determining the total prism power required calculating the effective prism power at 40 cm for the prism used, whether 10, 8, or 5 prism diopters, as well as the induced prism from looking off the optical center (OC) of the spectacle lenses. Since the target was placed directly in front of the right eye, the left eye performed all vergence movements. Thus it was necessary to determine the power of the left spectacle lens in the 180\textsuperscript{th} meridian to calculate the induced prism due to spectacle lenses. The power in the 180\textsuperscript{th} meridian was calculated by the equation: Power \( 180\textsuperscript{th} \) = Sphere Power + Cylinder Power \( \sin^2 \) (angle from cylinder axis to 180).\textsuperscript{21}

The DOG target was at 40 cm, creating a convergence demand under all prism conditions. As a subject viewed the target farther from the optical center of the lens, there was an increase in the induced prismatic effect of the spectacle lens, as calculated by Prentice's Rule: Induced Prism = displacement from the O.C. in cm \( \times \) Power of the lens in diopters.\textsuperscript{22} A subject wearing minus lenses would thus have an amount of BI prism induced by the spectacle lens that would increase with increasing convergence, and decrease with decreasing convergence. The result would be to decrease the relative BI and BO demand of the interjected prism. The reverse is true for a plus lens wearer, who would have an increase in the relative BO and BI effect of the interjected prism. See Appendix A for calculations, and Figs. 4 and 5 for illustration.

Data Analysis
The data were analysed using ANOVA of CA/C by decade and by half decade, of accommodative amplitude by decade and half decade, and of fixation disparity by decade. F-tests and Scheffe tests were utilized to determine statistical differences between groups, and to
determine which groups differed from each other. A two-way ANOVA of CA/C by add wear and half decade was performed. A two-way ANOVA of CA/C by add wear and accommodative amplitude was also performed.

Results

Fixation Disparity
There were no statistically significant differences in any of the fixation disparity data, by age group (p=0.27 to p=0.96) for any prism conditions. See Fig. 6. The BI prism generally resulted in eso FD's; plano, or no prism, resulted in exo FD's; and base out prism yielded exo FD's for all age groups.

Accommodative Amplitude
Looking at the age group means by decade, there was an expected difference in the accommodative amplitude (p=0.0001, F=40.7, df=3) between age groups. Table 2 and Fig. 7 illustrate the changes in accommodative amplitude data. The accommodative amplitude was essentially the same for the subjects in their 20's and 30's, followed by a continual decrease in amplitude from the 30's through the 50's. The Scheffe test showed there were statistically significant differences (p<0.05) in the accommodative amplitude with increasing age. A regression on age and Donders OU recovery gave an R value of 0.764.

Two way ANOVA on accommodative amplitude by half decade and add wear revealed a significant difference by age (p=0.0001), but no difference for add wearers (AW) versus non-add wearers (NAW), (p=0.7743). Fig. 8 and Table 3 illustrate this data.
CA/C Ratio
The CA/C ratio decreased with age, from age 25 to 54. For all groups of subjects, both AW and NAW, the mean CA/C values ranged from a high of 0.068 D/Δ to a low of 0.007 D/Δ. See Table 4 for CA/C values. Subjects were separated into half decades for analysis. Fig. 9 shows that the CA/C ratio from BI to BO increased slightly from the 20's to the early 30's, where a small peak occurred in the 30-34 age group, then declined in the 40's. The most precipitous drop in the CA/C occurred in the 45-49 age group. From age 50 to 54 there was a further slight decline. The difference between groups was significant (p=0.0001, F=3.985, df=1). The Scheffe F-test showed significant differences between subjects in their 20's and those 45 or older, those 30-34 versus those 40 and older, 35-39 versus 45 and older, and those 40-44 versus those 50 and older. A regression on CA/C and age yielded a pearson R value of -0.621.

After age 34, all subjects showed a continual age-related decline in the CA/C ratio, although the NAW retained insignificantly higher CA/C's with increased age (p=0.3944, F=0.733, df=1). When add wearers were excluded, the peak in the CA/C in the 30's was still evident, as seen in Fig. 10. The largest dissimilarity in the CA/C ratio for AW versus NAW was in the late 40's age group. In the 50's the CA/C for AW versus NAW was approximately the same.

When the total CA/C ratio is broken down into components, plano to BI and plano to BO, a slightly different response is seen for BI and BO prism conditions. See Table 5. Under plano to BI conditions there is a significant difference in CA/C ratios by age (p=0.0001, F=10.225, df=5) as seen in Fig. 11. But when separated by add use, as in Fig. 12, it is seen that prepresbyopic subjects who did not wear adds had slightly higher CA/C ratios in their 30's. The lines cross at
the 40-44 year old group, then the CA/C ratio is again higher for NAW. The difference between AW and NAW under plano to BI conditions was significant ($p = 0.0493, F=3.985, df=1$). There was an increase in the CA/C for NAW age 50-54, which may be due to the small number of subjects in that group, $N = 2$.

------Insert Fig.11, Fig. 12, and Table 5 about here------

When plano to BO responses were examined, there was a significant difference in CA/C by age group ($p = 0.0002, F=5.451, df=5$), but not by add wear ($p = 0.3102, F=1.034, df=1$). Fig. 13 illustrates the decline in CA/C for all subjects, plano to BO. Fig.14 shows the curves for AW versus NAW. AW have slightly higher CA/C's during the prepresbyopic years, and lower in the 40's, and higher again in the 50's, than do AW, but these differences are insignificant.

------Insert Fig.13 and Fig. 14 about here------

When the CA/C is plotted against accommodative amplitude rather than age, the relationship can be seen in Fig.15. The difference by accommodative amplitude was significant ($p=0.0022, F=3.812, df=6$). The difference by add wear was not significant ($p=0.06, F=3.624, df=1$). The interaction of the two was not significant ($p=0.0703, F=2.04, df=6$). A simple regression on accommodative amplitude versus CA/C for all subjects yielded a Pearson R value of 0.529. These data are tabulated in Table 6.

------Insert Fig.15 and Table 6 about here------

Discussion

Fixation Disparity

The fixation disparity data showed no significant differences for the different age groups, indicating there was essentially no alteration in the response to varying vergence demands with age. The amount of the disparity compared to the vergence demand of the prisms
indicates the subjects essentially responded fully to the interjected prisms.

The prisms used in the measurement of fixation disparity curves were also the ones used in the measurement of CA/C ratios. If a subject either could not achieve sensory fusion with the interjected prism, reporting diplopia or suppression, a lower prism power was used. In this manner the fixation disparity data served as a safeguard against suppression during the measurement of CA/C ratios.

**Accommodative Amplitude**
The decrease in the accommodative amplitude with increasing age comes as no surprise, as this has been well documented by many researchers for many years, beginning as early as Donders's graph in 1864. The decrease in accommodative amplitude from the 30's through the 50's is accompanied by a decrease in the CA/C ratio during the same years. This was also found by Fincham and Walton. As overall accommodative ability is decreased, convergence accommodation is utilized less.

There was a higher correlation for CA/C and age than for CA/C and amplitude of accommodation. Amplitude was measured with the Donder's Push Up method which, though easy to perform clinically, may not be the most accurate method of measuring amplitude. Measurement of accommodative amplitude among presbyopes may have been less accurate due to the use of near lens adds to obtain Donder's recoveries.

**CA/C**
Decreased CA/C with increasing age, or decreasing accommodative amplitude, has been noted by other researchers. Most of these studies on CA/C and age or on CA/C and accommodative amplitude have been cross sectional, but in Fincham and Walton's experiment seven of the subjects were retested after a lapse of two years. Of these seven, only one subject had no decrease in CA/C. That
subject was approximately only 20 years old at retesting, which is consistent with this study's data in that there was no decrease in CA/C for subjects in their twenties. All other subjects retested by Fincham and Walton had a decrease in the CA/C with increased age.

Bruce et al.\textsuperscript{14} found a reduced CA/C with increased age, and related it to different theories of the mechanism of presbyopia. They found a range of CA/C ratios from approximately 0.1 D/Δ at age 20 to 0.03 D/Δ at age 40,\textsuperscript{14} using a response/response technique. Schor\textsuperscript{13} found CA/C ratios that declined from 1.25 D/MA (0.208 D/Δ) at age 7 to 0.25 D/MA (0.042 D/Δ ) at age 39,\textsuperscript{13} but with a smaller sample size. Wick and Currie,\textsuperscript{17} reporting on six subjects, found CA/C ratios ranging from 0.17 D/Δ for a subject age 39, to 0.019 D/Δ for a subject age 42. Their subjects had a decline in CA/C with age, except for the 39 year old subject who had the largest CA/C.

The current study found a decline in the CA/C ratio with age, from a high of 0.068 D/Δ for subjects (AW and NAW combined) in their early thirties, declining to 0.004 D/Δ by age 54. A peak in the CA/C ratio occurred in the 30's, and a more rapidly declining CA/C was present in the late 40's. Subjects in their 40's who did not wear adds had insignificantly higher values in the CA/C ratio. This may indicate an adaptation or a maladaptation to decreasing accommodative amplitude in presbyopic non-add wearers. However, by the 50's the CA/C ratios for AW and NAW were essentially the same. The higher CA/C for NAW age 50-54, seen in Fig.12 may be due to the small number of subjects in that category. As any experienced clinician would expect, it was difficult to find subjects in their fifties who had never worn near addition lenses.

The present researchers wondered if there are any adaptations a person could employ to delay the need for near addition lenses, specifically the use of convergence accommodation to boost the declining response of reflex accommodation. That is to say, if the maximum amount of reflex accommodation has been achieved, could
an individual access more accommodation by stimulating an alternate neural pathway, i.e., that of convergence accommodation?

It seems that as the ability of an individual to accommodate declines, regardless of the exact mechanism of accommodative loss, the ability to respond with convergence accommodation will also be decreased, assuming the decreased amplitude is due to a mechanical restriction in the anatomical structures responsible for accommodation. From this study it appears convergence accommodation can be recruited by presbyopes through their 40's, and possibly slightly more so if add wear is avoided. But with increasing age the plant failure cannot be overcome by alternate innervation as presbyopia becomes complete, and the CA/C ratio declines to negligible levels.

There has been controversy among clinicians over the years as to which system is the lead system, i.e., does convergence lead accommodation, or vice versa. Fincham\(^6\) claimed convergence accommodation is responsible for the majority of accommodative effort, that one meter angle of convergence resulted in one diopter of accommodation, keeping convergence and accommodation balanced for a given target distance. He was of the opinion that reflex accommodation is used for "fine tuning" the accommodative response. Fincham and Walton\(^15\) found/believed monocular near stimuli would cause convergence which resulted in accommodation, that is to say, convergence leads accommodation. They found the convergence response to precede the accommodative response.

The peak in the CA/C that occurred in the late thirties may lend support to the hypothesis that people may utilize convergence accommodation to assist a declining reflex accommodation system. However, the peak in the CA/C occurs approximately 5 years prior to the noticeable decrease in accommodative amplitude. Prior research on CA/C and age also shows a peak in the late 30's or in the 40's,\(^13,14,15\) but with much smaller sample sizes. The fact that the same peak is not seen among the add wearers suggests that an
adaptive process may be occurring in non-add wearers that is not needed by add wearers due to the reduced amount of accommodation needed with add use, resulting in less stress on the accommodative system. Also, the higher CA/C ratio of AW in their 20’s may mean they are primarily utilizing convergence accommodation as opposed to reflex accommodation.

There was a slight drift toward a higher CA/C ratio for add wearers versus non-add wearers in the 40’s age group, when the decrease in accommodative amplitude becomes clinically significant, or associated with the onset of clinical presbyopia, suggesting a possible adaptation. According to Schor’s model, a low CA/C is associated with a low adaptation of tonic accommodation, with a high adaptation of tonic vergence. As presbyopia progresses and the accommodative amplitude declines, tonic accommodation is no longer able to adapt, and the CA/C ratio declines.

The traditional treatment for presbyopia is the use of near addition lenses, whether in spectacles or contact lenses. But is there a quicker decline in accommodative ability or skills once a person begins use of near lens adds? There is apparently no difference in accommodative amplitude, but convergence accommodation may be utilized as a greater percentage of the accommodative response. Can avoidance of near lens adds slow the progression of presbyopia? By age 54 the accommodative amplitude and CA/C ratio are both decreased to negligible levels.

Further research needs to be done to determine whether this observed peak in CA/C is significant and repeatable in non-add wearers, and whether it might occur in a different sample of add wearers. It would also be helpful to have a larger number of subjects age 50-54 to determine whether the subjects in this study are representative of their age group. Further research needs to be done to determine whether there is a significant difference in the CA/C ratio for add wearers versus non-add wearers.
References


Appendix A
Prism Calculations

Part I: Effective Prism Power at 40 cm

$P_e =$ effective prism power

$P_e = \text{prism power} \times \frac{1 - (a*/\text{target distance})}{1 - (2.68 \text{ cm}/40 \text{ cm})}$

*see calculation of 'a' in Part II

$P_e = 9.37\Delta$, for a $10\Delta$ at 40 cm.

Thus $x$, the displacement due to the interjected prism is:

$x = (\text{effective prism power}) \times \text{(target distance)}$

$x = 9.37\Delta \times (0.40 \text{ m})$

$x = 3.75 \text{ cm}$

$x$ is: (+) for BO,

(-) for BI.

Part II: Calculation of Induced Prism From Spectacle Lens

Variables:

distance from eye to spectacle plane = 12 mm

$a =$ distance from center of rotation of eye to spectacle plane, a constant (14.8 mm + 12 mm = 26.8 mm)

$a = 2.68 \text{ cm}$

$b =$ distance from center of rotation of eye to target, also a constant

$(a + 40 \text{ cm} = 2.68 \text{ cm} + 40 \text{ cm} = 42.68 \text{ cm})$

$b = 42.68 \text{ cm}$

c = interpupillary distance of subject
$x$ = amount of displacement caused by the interjected prism
$y$ = amount of displacement in lens caused by target at 40 cm
$y'$ = amount of displacement caused by the interjected prism

Using like triangles:
\[
\frac{a}{y + y'} = \frac{b}{c + x} \quad \text{OR} \quad y' = \frac{a(c+x)}{b} - y
\]

Thus: $y'$ (power of the lens in the 180th meridian) = $P_S$
where $P_S$ = induced spectacle prism.

To solve for $y$ using like triangles:
\[
\frac{a}{y} = \frac{b}{c}
\]

\[
y = \frac{ac}{b}
\]

Substituting into the original formula, $y' = \frac{a}{b(c+x)} - y$,
\[
y' = \frac{a}{b(c+x)} - \frac{ac}{b}
\]
\[
y' = \frac{ax}{b}.
\]

Therefore, $y' = \frac{(2.68 \text{ cm}) (3.75 \text{ cm})}{42.68 \text{ cm}}$
\[
y' = 0.24 \text{ cm}.
\]

Therefore, $P_S = (\pm 0.26 \text{ cm})$ (spectacle power in 180th meridian).

$P_S$ will be: (+) with BO and a (+) lens; additive effect
(-) with BO and a (-) lens; subtractive effect
(+) with BI and a (-) lens; subtractive effect
(-) with BI and a (+) lens; additive effect

Thus a (+) lens will always increase both BO and BI effects, and
a (-) lens will always decrease both BO and BI effects.

$P_t$ = total prism introduced to the eye,
\[
= \text{induced spectacle prism} + \text{effective prism power}
\]

$P_t = P_S + P_e$. 

Fig. 1. Schor's Model of Accommodation and Convergence Interactions

- **Blur**
  - Phasic Accommodation
  - Tonic Accommodation
    - CA/C

- **Disparity**
  - Phasic Vergence
  - Tonic Vergence
    - AC/A

- **Accommodative Response**
- **Vergence Response**
Table 1. Subjects

<table>
<thead>
<tr>
<th>Age</th>
<th>Non-add Wearers</th>
<th>Add Wearers</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>25-29</td>
<td>12</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>30-34</td>
<td>17</td>
<td>5</td>
<td>22</td>
</tr>
<tr>
<td>35-39</td>
<td>8</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>40-44</td>
<td>8</td>
<td>9</td>
<td>17</td>
</tr>
<tr>
<td>45-49</td>
<td>1</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>50-54</td>
<td>2</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>Total</td>
<td>48</td>
<td>45</td>
<td>93</td>
</tr>
</tbody>
</table>
Fig. 2. Difference of Gaussian (DOG) Target
Fig. 3. Schematic of Set-up

Interjected Prism
Spectacle Lens

DCG Target at 40 cm
Optometer
Fig. 4. Image Displacement

- Upper arrow: due to interjected prism
- Lower arrow: due to induced prismatic effect of spectacle lens

Induced BO: increases with increasing convergence
decreases with decreasing convergence
Fig. 5. Image Displacement
- Due to interjected prism
- Due to induced prismatic effect of spectacle lens
  Induced BI: decreases with increasing convergence
  increases with decreasing convergence
Fig. 6. Fixation Disparity

![Graph showing fixation disparity with age groups: 20's, 30's, 40's, 50's. The graph illustrates the relationship between prism condition and fixation disparity.]
<table>
<thead>
<tr>
<th>Decade</th>
<th>mean (cm)</th>
<th>s.d. (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20's</td>
<td>9.625</td>
<td>2.66</td>
</tr>
<tr>
<td>30's</td>
<td>10.7</td>
<td>3.75</td>
</tr>
<tr>
<td>40's</td>
<td>24.82</td>
<td>10.82</td>
</tr>
<tr>
<td>50's</td>
<td>37.75</td>
<td>15.42</td>
</tr>
</tbody>
</table>
Fig. 7. Accommodative Amplitude by Decade

![Graph showing accommodative amplitude by decade](image-url)
Fig. 8. Accommodative Amplitude by Add Wear

![Graph showing accommodative amplitude by age and add wear](image)
<table>
<thead>
<tr>
<th>Age</th>
<th>Add Wearers</th>
<th>Non-add Wearers</th>
</tr>
</thead>
<tbody>
<tr>
<td>25-29</td>
<td>7.3</td>
<td>10.4</td>
</tr>
<tr>
<td>s.d.</td>
<td>1.56</td>
<td>2.5</td>
</tr>
<tr>
<td>30-34</td>
<td>8.6</td>
<td>10</td>
</tr>
<tr>
<td>s.d.</td>
<td>2.95</td>
<td>2.32</td>
</tr>
<tr>
<td>35-39</td>
<td>13.2</td>
<td>12.5</td>
</tr>
<tr>
<td>s.d.</td>
<td>5.3</td>
<td>5.32</td>
</tr>
<tr>
<td>40-44</td>
<td>20.3</td>
<td>19.4</td>
</tr>
<tr>
<td>s.d.</td>
<td>3.03</td>
<td>8.81</td>
</tr>
<tr>
<td>45-49</td>
<td>33</td>
<td>27</td>
</tr>
<tr>
<td>s.d.</td>
<td>12.75</td>
<td></td>
</tr>
<tr>
<td>50-54</td>
<td>35.5</td>
<td>51.5</td>
</tr>
<tr>
<td>s.d.</td>
<td>10.64</td>
<td>37.48</td>
</tr>
</tbody>
</table>
Fig. 9. CA/C BI to BO All Subjects
<table>
<thead>
<tr>
<th>Age</th>
<th>Non-add Wearers</th>
<th>Add Wearers</th>
<th>All Subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>25-29  mean</td>
<td>0.054</td>
<td>0.07</td>
<td>0.058</td>
</tr>
<tr>
<td>s.d.</td>
<td>0.028</td>
<td>0.047</td>
<td>0.033</td>
</tr>
<tr>
<td>30-34  mean</td>
<td>0.069</td>
<td>0.065</td>
<td>0.068</td>
</tr>
<tr>
<td>s.d.</td>
<td>0.028</td>
<td>0.027</td>
<td>0.027</td>
</tr>
<tr>
<td>35-39  mean</td>
<td>0.058</td>
<td>0.052</td>
<td>0.056</td>
</tr>
<tr>
<td>s.d.</td>
<td>0.023</td>
<td>0.026</td>
<td>0.023</td>
</tr>
<tr>
<td>40-44  mean</td>
<td>0.046</td>
<td>0.038</td>
<td>0.042</td>
</tr>
<tr>
<td>s.d.</td>
<td>0.015</td>
<td>0.024</td>
<td>0.02</td>
</tr>
<tr>
<td>45-49  mean</td>
<td>0.043</td>
<td>0.013</td>
<td>0.015</td>
</tr>
<tr>
<td>s.d.</td>
<td>0.008</td>
<td>0.012</td>
<td></td>
</tr>
<tr>
<td>50-54  mean</td>
<td>0.011</td>
<td>0.007</td>
<td>0.007</td>
</tr>
<tr>
<td>s.d.</td>
<td>0.021</td>
<td>0.018</td>
<td>0.018</td>
</tr>
</tbody>
</table>
Fig. 10. CA/C BI to BO

[Graph showing the CA/C ratio in different age groups for Add and No Add conditions.]
Fig. 11. CA/C Plano to Bl, All Subjects
Fig. 12. CA/C, Plano to BI

![Graph showing the relationship between age and CA/C ratio for 'Add' and 'No Add' conditions.]
<table>
<thead>
<tr>
<th>Age</th>
<th>CA/C: PL-Bi</th>
<th>CA/C: PL-BO</th>
<th>CA/C: BO-Bi</th>
</tr>
</thead>
<tbody>
<tr>
<td>25-29</td>
<td>0.073</td>
<td>0.043</td>
<td>0.058</td>
</tr>
<tr>
<td></td>
<td>0.051</td>
<td>0.038</td>
<td>0.033</td>
</tr>
<tr>
<td>30-34</td>
<td>0.082</td>
<td>0.054</td>
<td>0.068</td>
</tr>
<tr>
<td></td>
<td>0.04</td>
<td>0.033</td>
<td>0.027</td>
</tr>
<tr>
<td>35-39</td>
<td>0.068</td>
<td>0.043</td>
<td>0.056</td>
</tr>
<tr>
<td></td>
<td>0.045</td>
<td>0.036</td>
<td>0.023</td>
</tr>
<tr>
<td>40-44</td>
<td>0.039</td>
<td>0.044</td>
<td>0.042</td>
</tr>
<tr>
<td></td>
<td>0.032</td>
<td>0.031</td>
<td>0.02</td>
</tr>
<tr>
<td>45-49</td>
<td>0.016</td>
<td>0.014</td>
<td>0.015</td>
</tr>
<tr>
<td></td>
<td>0.014</td>
<td>0.016</td>
<td>0.012</td>
</tr>
<tr>
<td>50-54</td>
<td>0.011</td>
<td>0.004</td>
<td>0.007</td>
</tr>
<tr>
<td></td>
<td>0.026</td>
<td>0.037</td>
<td>0.018</td>
</tr>
</tbody>
</table>
Fig. 13. CA/C Plano to BO, All Subjects
Fig. 14. CA/C, Plano to BO by Add Wear

![Graph showing CA/C values with and without add wear over age range 25-54 years. The graph compares the CA/C values for add wear and no add wear conditions, with age categories from 25-29 to 50-54 years.](image)
Fig. 15. CA/C BO to BI by Accommodative Amplitude
<table>
<thead>
<tr>
<th>Acc. Amp. (D)</th>
<th>&gt;10.00</th>
<th>6.67-9.99</th>
<th>5.00-6.66</th>
<th>4.0-4.99</th>
<th>2.87-3.99</th>
<th>2.22-2.86</th>
<th>&lt;2.22</th>
</tr>
</thead>
<tbody>
<tr>
<td>Add Wearers mean</td>
<td>0.071</td>
<td>0.022</td>
<td>0.05</td>
<td>0.031</td>
<td>0.009</td>
<td>0.008</td>
<td>0.012</td>
</tr>
<tr>
<td>s.d.</td>
<td>0.034</td>
<td>0.022</td>
<td>0.017</td>
<td>0.026</td>
<td>0.006</td>
<td>0.029</td>
<td>0.018</td>
</tr>
<tr>
<td>Non-add Wearers mean</td>
<td>0.056</td>
<td>0.064</td>
<td>0.057</td>
<td>0.039</td>
<td>0.043</td>
<td>0.03</td>
<td>0.025</td>
</tr>
<tr>
<td>s.d.</td>
<td>0.029</td>
<td>0.024</td>
<td>0.026</td>
<td>0.037</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>All Subjects mean</td>
<td>0.075</td>
<td>0.064</td>
<td>0.054</td>
<td>0.04</td>
<td>0.016</td>
<td>0.009</td>
<td>0.015</td>
</tr>
<tr>
<td>s.d.</td>
<td>0.043</td>
<td>0.05</td>
<td>0.04</td>
<td>0.04</td>
<td>0.011</td>
<td>0.03</td>
<td>0.012</td>
</tr>
</tbody>
</table>