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Comparison of Three Clinical Tests of Accommodation to Hofstetter's Norms to Guide Diagnosis and Treatment

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A Comparison of Three Clinical Tests of Accommodation to Hofstetter's Norms to Guide Diagnosis and Treatment

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Abstract

PURPOSE: It has been documented previously that the push up (PU) and pull away (PA) methods overestimate accommodative amplitude (AA), while the minus lens-to-blur (MLB) method underestimates it. It also has been shown that the PU and PA methods produce similar results. We sought to compare data obtained from these three clinically used methods to determine AA in children and young adults with base-line normative data predicted by Hofstetter.

METHODS: Ninety healthy subjects (mean 11.7 years, range: 6-36 and 50F/40M), split into two groups, children (mean 9.8 years, range: 6-13 and 38F/22M) and young adults (mean 25.5 years, range: 21-36 and 16F/14M), were recruited from the patient and student populations of two schools of optometry. The subjects completed three accommodative tests presented in a random order: PA, PU, and MLB methods.

RESULTS: Findings from the MLB technique varied significantly from Hofstetter's normative values ($P<0.000$). The PU ($P=0.83$) and PA ($P=0.28$) methods were similar to Hofstetter's normative values in younger subjects. The PU ($P=0.76$), but not the PA ($P=0.033$) method was similar to Hofstetter's normative values in the oldest adults tested. Significant differences were not found between the PU and PA values for either age group ($P=0.31$-Adults, $P=0.56$-Children).

CONCLUSIONS: As compared with Hofstetter's normative values, this study demonstrates that the MLB technique gives a lower AA in children, while the PU and PA methods yielded consistent findings with each other and with Hofstetter's normative values. The PU method yielded values that compared closest with Hofstetter's normative data for the oldest subjects

tested in this study and indicates that the most consistent methods to measure AA in children is either the PU or PA methods, and the PU method for adults.

Chapter 1: INTRODUCTON and LITERATURE REVIEW

1.1 The establishment of normative data for amplitude of accommodation as a function of age.

The study of amplitude of accommodation (AA) dates back almost 150 years. The first study regarding amplitude of accommodation and age is credited to Donders.[1] He recognized three types of accommodation: absolute, binocular and relative. He used only subjects that were emmetropic or nearly emmetropic, investigating 130 individuals, ranging in age from 10 to 80 years. The testing procedure involved the selection of the maximum plus or minimum minus lenses, which permitted maximum acuity at distance through which was determined the nearest point of clear vision. He used a bench optometer and a set of five fine vertical wires as the target to detect blur. For absolute accommodation, the farthest and nearest points of clear vision were measured for each eye. For binocular accommodation, the same points were measured under a binocular viewing condition. Relative accommodation was measured by the addition of convex and concave lenses binocularly while maintaining a given convergence. This was done to keep the lines of sight remaining parallel. When the near point of the absolute and binocular accommodation was farther than 22cm, convex lenses were added to image it closer. Measurements were made with respect to the nodal point of the eye (7mm behind the vertex of the cornea). The amplitude was represented as the difference between the near and far point values. AA values are presented in Figure 1 as a function of age according to Donders. Data are not considered to be purely binocular or monocular.

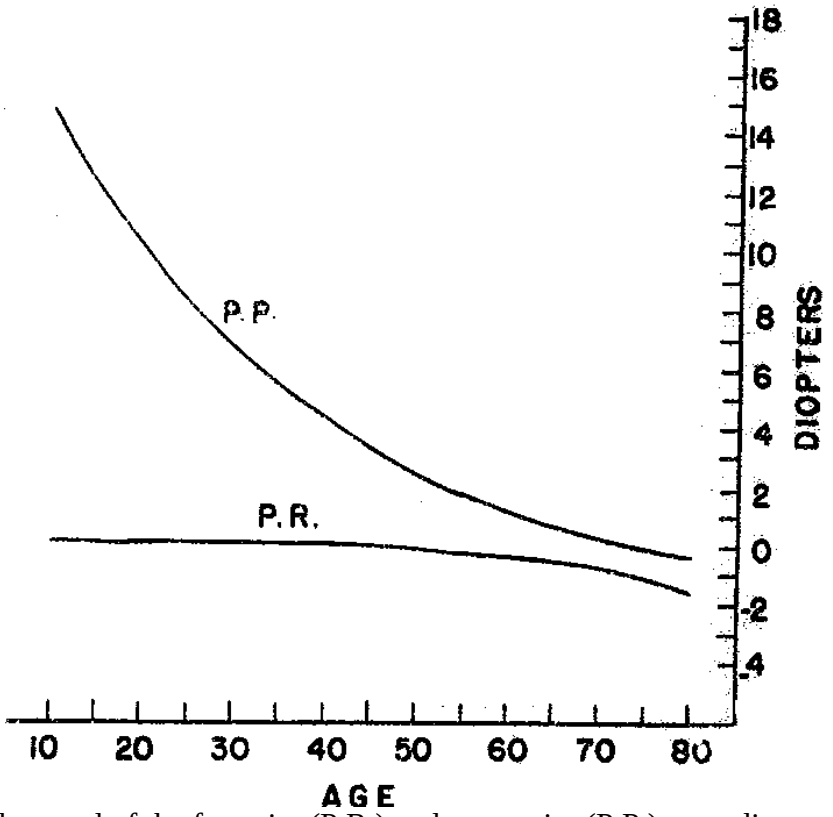

Figure 1: The trend of the far point (P.R.) and near point (P.P.) according to Donders.

Kaufman investigated AA in 400 eyes (200 subjects) in 1894. Similar to Donders, he used positive lenses when the near point exceeded 22 cm but used a reading card on "most cases."[2] On review of Kaufman's study, it is presumed that his measurements were taken monocularly. The results of Kaufman's study supported those of Donders.[1]

Duane presented findings from 4000 eyes in two papers in 1909 and 1912.[3,4] These are the values with which many of the theories and formulas concerning amplitude of accommodation are based. The subjects ranged in age from eight to 70 years. The target was a white card with a single black line measuring 0.2 mm thick and 3.0 mm long. No subject with vision poorer than 20/20 was utilized and those with high astigmatism, high myopia, amblyopia or ocular disease were excluded from the study. Testing was performed monocularly with full distance correction applied.

The testing procedure included the use of a -3.00 or -4.00 D lens for young subjects "so as to carry the nodal point out beyond 10cm."[3(p. 1993)] Plus lenses were used whenever the near point was beyond 40 cm. The values of the lenses were subsequently subtracted or added from the result.[3,4] To minimize the possibility of failure on the part of the subject to maximize accommodative effort, Duane resorted to repeated testing and carefully worded instructions to the subject. Each recorded amplitude represented the highest value obtained for the eye being tested.

Three differences were noted by Duane in making a comparison to Donders' work:

1) Prior to the age of 20 years, Duane's curve falls below that of Donders'.

2) From 20 to 45 years, Duane's curve rises above the Donders' curve.

3) From 45 years onward, Duane's curve falls below Donders' curve and a sharp plunge takes place between 38 and 50.[4] (Figure 2) Duane suggested that differences were due to the small number of cases reviewed by Donders and the difficulty getting accurate results when accommodation is high and the subjects are young.

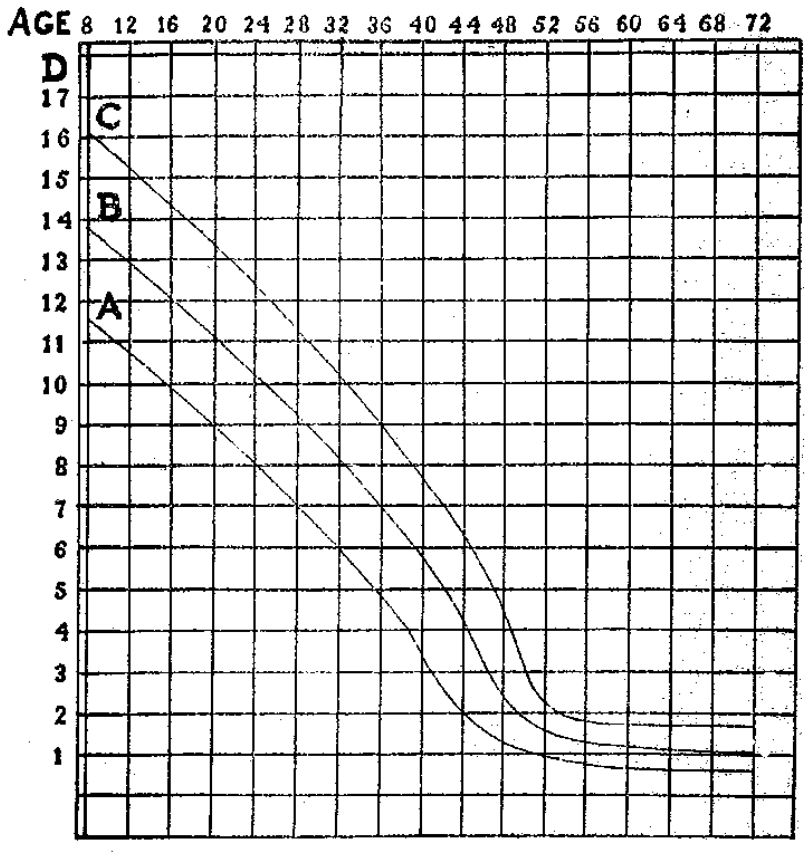

Figure 2: Accommodation curve according to Duane. A-the extreme minimum, B-normal values (mean value of the accommodation), C-extreme maximum

Turner, making both monocular and binocular measurements, with reference to the spectacle plane reported the amplitude of accommodation in 500 subjects (1000 eyes) using the PU method. Subjects ranged in age from 13 to 67 years. Full distance correction was used during testing. A card with a paragraph of .75 M print was brought closer to the subject until the print began to blur. After this point was reported, the card was brought several centimeters closer and then moved away from the subject until the print became clear again. This point was recorded as the recovery point.[5]

If the subject's near point of accommodation exceeded 30 cm, a +2.00 or +3.00 lens was added to the trial frame. If it was less than 12 cm, a -3.00 or -4.00 lens was added. This was done to prevent the test target from getting too close or far from the subject during measurement.

> Turner's findings were lower by an average of 1.30D (+/-.82D, p=0.0004) as compared with Duane's data. Turner suggested the following factors to account for this discrepancy and concluded that Duane's findings were doubtful and appeared too high.[5]

1) Duane used the first blur as his criterion while Turner used the recovery point.

2) The targets used are dissimilar. Duane's target, a single black line may have given a less clear end–point versus the print used by Turner.

3) Turner measured from the midline of the two eyes, but Duane did so from straight-ahead.

Hofstetter[6] made a detailed comparison of the work of both Donders and Duane. He indicated that Donders' findings, once corrected for the spectacle plane were in fact higher than Duane's findings. He concluded that:

1) The higher findings obtained by Donders in the range of ages less than 20 years cannot be considered significant due to reduced accuracy of measurement.

2) Higher values found by Donders between the ages of 40-60 years may be due to a difference in procedure which was more pronounced for low amplitudes.

3) An analysis did not justify the use of any specific curve to represent the trend of the amplitude with age. For clinical purposes, it would be convenient to use a straight line to represent changes in accommodation expected with age and this would be nothing more than a compromise of Donders' and Duane's findings.

4) Measured amplitude decreased at the rate of 0.3 diopters per year until it reached a value of 0.50 D at the age of 60 years, after which no decrease was found.

In a subsequent article,[7] Hofstetter produced a graphical representation of the above-referenced rule (Figure 3). It is a straight line extending from a value of 0.50 D at the age of 60 to 18.5 D at the age of zero. The rule was stated mathematically as Probable Amplitude = 18.5-.3(age). He defined the high and low extremes by the following formulas respectively, Maximum Amplitude = 25-.4(age) and Minimum Amplitude = 15-.25(age). The two lines represented the maximum and minimum values enclosing almost all of the original data from Duane and Donders and data was assumed to lay approximately two standard deviations from the mean.

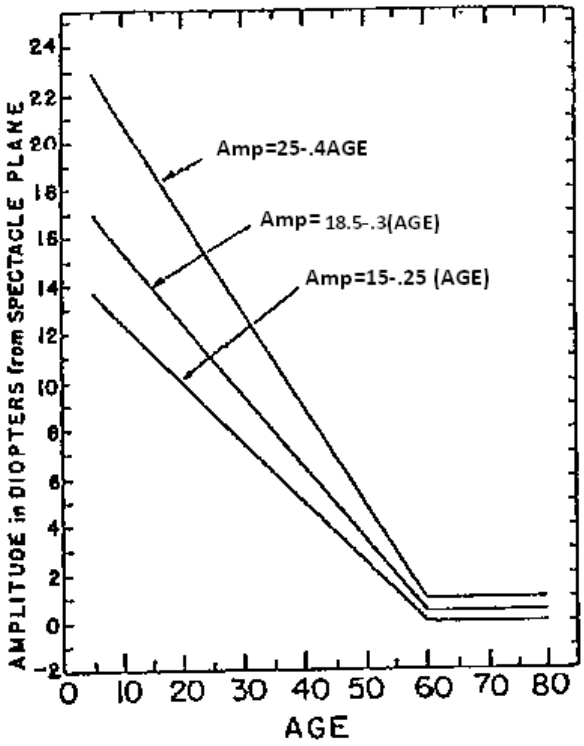

Figure 3: Accommodation curve according to Hofstetter. Top curve-Maximum amplitude, Middle curve-Probable or expected amplitude, Bottom curve-Minimum amplitude

1.2 A Comparison of Clinical Studies Investigating Amplitude of Accommodation

Sheard [8], using small letters on a card instead of a line, utilized concave (minus) lenses with the test target at one-third of a meter to measure the monocular amplitude of accommodation in children and adults age 10-40 years. Lenses were added in increasing strength until the letter first became "indistinct." He found that using the concave lens method yielded less AA than the data reported by Donders and Duane using a near point method. Knowing that the effect of concave lenses is to minimize the retinal image size, and therefore the size of the test object, he surmised that it should be expected that the concave lens method would produce lower amplitudes than the near point methods developed previously.

Coates[9] studied the AA of approximately 4000 eyes of South Africans using an Orthops rule. The target, a single word (1M) printed on art paper, was presented monocularly. The average of the first blur and recovery position was recorded. The amplitude was found to be about 1D or 5 years below expected means put forth by Duane. He found that there was no difference between South African natives or Bantu, Colored South Africans (described as a mixture of European, African and Asian), South African Indians and European South Africans. Coates put forth that climate (more hours of sun per day, greater intensity of sunlight, food (smaller amounts of certain vitamins: longer cooking leads to a greater reduction in vitamins) and race could account for the difference between his data and Duane's.

Schapero and Nadell[10] measured the AA in 16 subjects aged 30-74 years. Using the PU method, subjects were asked to indicate the first blur. It was found that Duane's findings were in closer agreement than Donders and the authors suggested that the findings were due to the fact that Duane's procedure took measurements with less plus.

Eames, attempting to study a theory that proposed that "children enter school before their eyes mature enough to cope with demands made on them by the curriculum,"[11(p.1255)] studied 899 five- to eight-year-old children. PU testing was performed binocularly as this "involves a certain amount of convergence influence and give data that are more applicable to practical school room problems." [11 (p. 1255)] He separated the testing groups into urban and suburban, finding that means for suburban cases approximated those of Duane at the same age. Urban children showed a mean 5.1 diopters less than the suburban group with larger differences occurring in younger children. It was surmised that education, nutrition, physical development and even "poorer biologic material,"[11 (p. 1257)] might impact visual testing, including AA.[11]

Kajiura measured AA in emmetropic (n=771), hyperopic (n=328) and myopic (n=552) eyes using the PU method. He concluded that the age of presbyopia onset in Japan in 1965 was 47 years in contrast to 43 years, which was recorded in 1919. The four year difference is close to the more commonly cited difference of five years that is used regarding the onset of presbyopia in tropical versus temperate climates. He attributed this difference to the greatly improved physique and increased life expectancy of the Japanese since WWII, due to better diet and improved living conditions.[12] Kragha, in an evaluation of the study, indicated that was possible that at the time of the article (1965) there was a higher proportion of myopes in Japan in respect to the previous fifty years and other countries. It was concluded that "optical effectivity will thus give an apparently greater amplitude of accommodation."[13 (p. 76)]

Beers et al.[14] in an investigation of 20 subjects (15-55 year old) formulated an equation (Max AA=11.9-0.19 X age) that established the maximum monocular AA based on age. Beers and colleagues used ultrasonographic biometry to measure the far-to-near and near-to-far accommodation of the ciliary muscle. Each measurement was performed 10 times on each

subject to determine the maximum AA. While he found a direct correlation between age and amplitude, he also reported that accommodation became slower with age.

Sterner et al.[15] investigated AA in 76 children aged 6-10 years using Donders' PU method. The results showed lower amplitude as compared with Hofstetter's equations. Also, the findings were lower than those previously reported.[1,5,16] The average dioptric difference was -3.50 and -3.60 for the right and left eye respectively. They reported that approximately 50-60% of the subjects had monocular amplitudes lower than Hofstetter's minimum reference line. On average, children had amplitudes 0.50 D lower than the minimum reference line.

Acknowledging the lack of published data concerning AA in young children, Wold[16] obtained measurements on 125 grade school children, ages 6 to 10, using eight different techniques. These tests included an objective measure in the form of retinoscopy and seven subjective measures (monocular and binocular), including concave sphere to first blur, letter target push-up to first blur and parallel thread target push-up to first blur.

The "concave sphere to first blur" was performed binocularly, similar to a test currently referred to as the Positive Relative Accommodation (PRA). Once the end point of the first blur was obtained, one eye was occluded and greater amounts of minus were added until first monocular blur was found for each eye separately. The monocular procedure was then repeated.

The technique referred to as the "letter target push-up to first blur" test was comparable to Duane's. Using a near point reduced Snellen card, a -4.00 or -6.00 diopter lens was used to keep the measured near point beyond 10 centimeters. This would theoretically reduce error in measurement, as the closer the distance the more important the preciseness of measurement becomes. Duane used lens powers of -3.00 or -4.00 D. A similar procedure was used with

"parallel thread target push-up to first blur" except that the target was two black threads each 0.2mm wide separated by 0.3mm.

The results indicated that there were differences among the different test results. Over the entire sample, the letter target push-up test (18.37D +/- 2.82D) compared well with Donders' data. The concave sphere (13.62 D +/-2.75 D) and parallel-thread target push-up test (16.75 D +/- 2.56 D) produced lower amplitudes. The authors suggested that the tests were not interchangeable.[16]

Looking at the Pearson Product-Moment Correlation Coefficients (r) of the Monocular Letter Target push-up, Monocular Concave Sphere test and Monocular Parallel Thread Target push-up, it is evident that the push-up tests do not correlate as well with the concave lens procedure. (Letter target: r=0.592, Parallel Thread target: r=0.543) The two push-up tests on the other hand do correlate well to each other. (r=0.854)[16]

Where the PU method has been compared with methods that should be free of depth-of-focus effects, the PU method gave higher results by 1.5 to 2.5 D.[17-20] Hamasaki et al. in a study of 106 subjects (212 eyes), ages 42 to 60 years, found that the PU technique overestimates AA by about 2D.[17]

A study by Kragha[13] supported Hamasaki's findings. A chart review of 447 Nigerian subjects (894 eyes), ages 9 to 62 years was performed. Both the MLB and PU methods were employed. Using a target consisting of .4M or best near-point visual acuity letters, the distance at which the first blur was reported was determined in diopters for the PU method. The MLB method procedure consisted of the same size print placed at 40cm while lenses of increasing power were added until first blur was reported. Both procedures were performed monocularly.

The PU amplitude of accommodation was found to be 1.72 diopters greater than the minus lens value. (P=0.0000) While there was agreement between four sets of data from different age groups, it was reported that the difference in AA in subjects below the age of 20 could not be considered significant due to the reduced accuracy of measurement as first reported by Hofstetter.[6]

A variation of the PU technique, the PA method has been investigated as an alternative. This alteration involves placing the target close to the subject and slowly pulling it away until the target can be identified. Pollock[21], Woehrle et al.[22] and Chen[23] showed that there was no significant difference in the amplitudes found between the two techniques. Each study included a wide age range of subjects: Pollack 10-45 years, mean 22 years, n=12;Woehrle 10-40 years, mean 15 years, n =25; Chen 7-28 years, mean 23 years, n=29.

Rosenfield and Cohen not only compared the PU and PA methods, but also the MLB method in 13 visually normal subjects, age 23-29 years. The mean values of the three techniques were significantly different from each other. The PU technique provided the highest amplitude which was in agreement with Donders and Duane studies. The PA and MLB methods differed by 0.61 D and 1.01 D respectively.[24]

In this review of the literature encompassing studies to determine AA, there continues to be debate among researchers and practitioners as to the correlation of these techniques in all age groups, especially in children. These procedures are used to determine accommodative function and help to guide treatment of accommodative conditions such as accommodative insufficiency, excess and infacility.

1.3 Purpose

A significant cause of academic performance difficulty is undetected visual problems.[25] The most frequently encountered condition in optometry after refractive error is a binocular, accommodative or ocular motor anomaly.[25] The prevalence of undetected vision problems among school children has been documented to be approximately 20 to 22 percent.[25, 26] A study conducted by Scheiman included 2023 consecutive subjects between the ages of 6 months and 18 years and found 19.7% had a binocular or accommodative dysfunction. This was further categorized into convergence excess (7.1%), convergence insufficiency (4.6%), accommodative insufficiency (2%) and accommodative excess (1.8%).[25] Similarly, Lara et al. found the overall prevalence of binocular and accommodative dysfunctions at 22.3% in a study size of 265 subjects aged 10-35 years. This was further categorized into accommodative insufficiency (3%), accommodative excess (6.4%), convergence excess (4.5%), convergence insufficiency (0.8%) and multiple diagnoses (7.2%).[26]

Accommodative dysfunction accounts for approximately 4-10% of learning related vision problems.[25,27] Patient complaints include but are not limited to: headaches, eye strain and blurry vision at near. A retrospective review of 54 cases with a diagnosis of accommodative insufficiency by Bartuccio, Taub and Keiser[28] reported that the most common complaints found were distance blur (37%) followed by headaches (14.8%), both distance and near blur (13%) and near vision blur only (9%). Other common complaints included routine exam/no complaint (7.5%), reading avoidance (3.7%), tracking/reading problems (3.7%) and poor reading/perceptual skills (3.7%). Of the 54 patients in this study the refractive error breakdown was as follows: 30 (56%) myopia, 20 (37%) emmetropia, 4 (7%) hyperopia. In a retrospective review of 96 subjects diagnosed with accommodative insufficiency, Daum reported that the

incidence of blur was 56%, headache-56%, asthenopia-45%, and diplopia-45%.[29] In the case of accommodative insufficiency, some patients do not report any symptoms.[30] Any decrease in accommodative function among school children can contribute to near-work related problems and thus, can have a negative effect on a child's learning experience.[31]

The treatment of accommodative dysfunction, including accommodative insufficiency and spasm as well as ill-sustained accommodation, includes the correction of refractive error followed by an assessment for the use of plus lenses at near. These lenses can be used as a standalone treatment or in conjunction with vision therapy. If the patient does not respond to plus at near, vision therapy is used as the primary treatment regimen. Testing of the AA (PU, PA, MLB), accommodative response (monocular estimated method) and accommodative facility (monocular and/or binocular) helps determine current function and the most appropriate treatment.[30]

It has been previously documented that the PU and PA methods overestimate AA due to relative magnification while the MLB underestimates it secondary to lens minification.[30] This occurs as the patient views the target under increasingly greater minus lens strengths. It has also been shown that the PU and PA methods produce similar results.[21-23] Both the average and minimum amplitude for a given subject can be predicted using Hofstetter's equations, which are based on Duane and Donderss' tables describing expected findings by age. The formula for average amplitude is 18.5-.3(age), while the formula for minimum amplitude is 15-1/4(age). The purpose of this study is to compare findings from these three widely used methods to measure AA as a function of age in normal healthy subjects and to relate findings to the accepted base-line normative data predicted by Hofstetter. Findings should assist in the diagnosis and

treatment of conditions associated with change in AA or disorders associated with amplitude of accommodation.

Chapter 2. GENERAL METHODOLOGY

2.1 Subjects

Ninety healthy subjects (mean 16.63 years, range: 6-36 and 50F/40M), split into two groups, children (mean 9.8 years, range: 6-13 and 38F/22M) and young adults (mean 25.5 years, range: 21-36 and 16F/14M) with best corrected visual acuity (at least 20/20) participated in this study. All subjects had no history of strabismus or amblyopia. An exclusion criterion was set at an AA of greater than 25D as this is the greatest amount possible on the upper amplitude range as per Hofstetter's formula for maximum AA (25-.4age) at the age of zero.[7] Nine young subjects were excluded from the study secondary to this criterion.

Subjects were recruited from the patient and student populations of the Colleges of Optometry from Nova Southeastern University and Southern College of Optometry. The study adhered to the tenets of the Declaration of Helsinki and was approved by the IRB of both Nova Southeastern University in Ft. Lauderdale, Florida and Southern College of Optometry in Memphis, Tennessee for the protection of human subjects. Informed consent was obtained from adult participants and parental consent and the child's assent was obtained for all participants less than 18 years of age.

2.2 Procedure

Right eye measurements were obtained for the three accommodative tests: the PA, PU, and MLB methods. Each procedure was performed four times. The first measurement of each test was eliminated from analysis to control for variability due to practice effects. Measurements

2-4 were averaged for each of the three methods. Order of test presentation was controlled, using a random order table. All measurements were recorded while the left eye was fully occluded.

2.2.1. Pull away measurements

For the PA measurement, subjects monocularly viewed a high contrast, black and white near-point card, (Bernell) (Figure 4) while wearing their habitual prescription either in the form of spectacles or contact lenses. Using the Accommodation Convergence Rule (Bernell) (Figure 5), which was placed in the primary fixation position, on the brow above the eye being tested, subjects were asked to view a single line of text (.6M) on the near-point card. The target was placed 0.5 cm in front of the subject's right eye, so the print could not be read. The target was brought away from the subject's face in a smooth manner until the subject reported that he or she could identify a specified letter on the .6 M acuity line.

Figure 4: The near point card used during testing

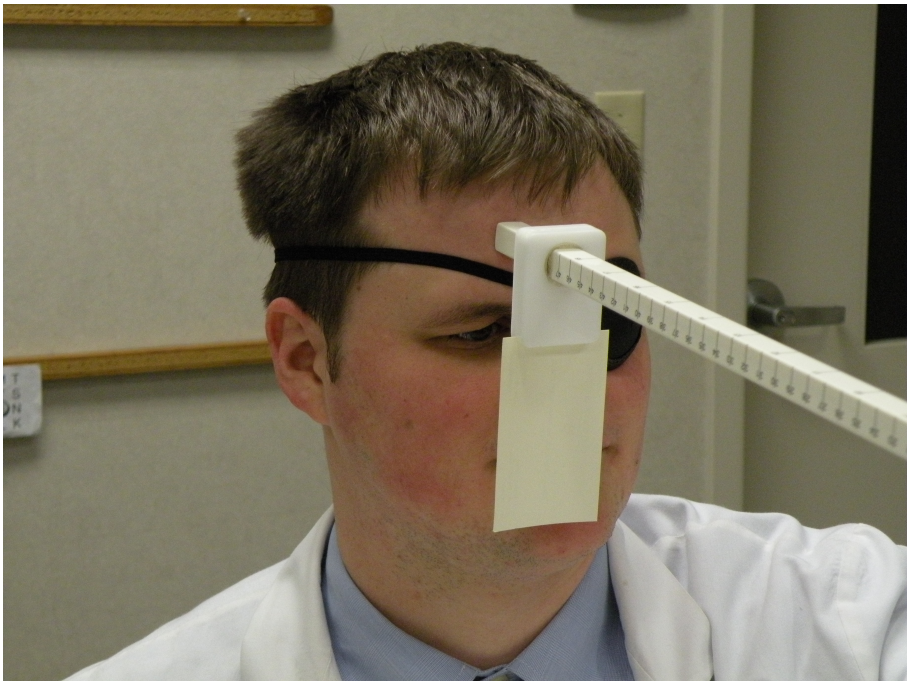
Figure 5: Pull-away method demonstration

2.2.2. Push-up measurement

For the PU measurement, subjects monocularly viewed a high contrast, black and white near-point card, (Bernell) while wearing their habitual prescription either in the form of spectacles or contact lenses. Using the Accommodation Convergence Rule (Bernell) (Figure 6), which was placed in the primary fixation position, on the brow above the eye being tested, subjects were asked to view a single line of text (.6M) on the near-point card. The target was placed in front of the subject's right eye at 40cm and brought closer to the subject until the first sustained blur was reported. The speed of the target was the same as the PA method.

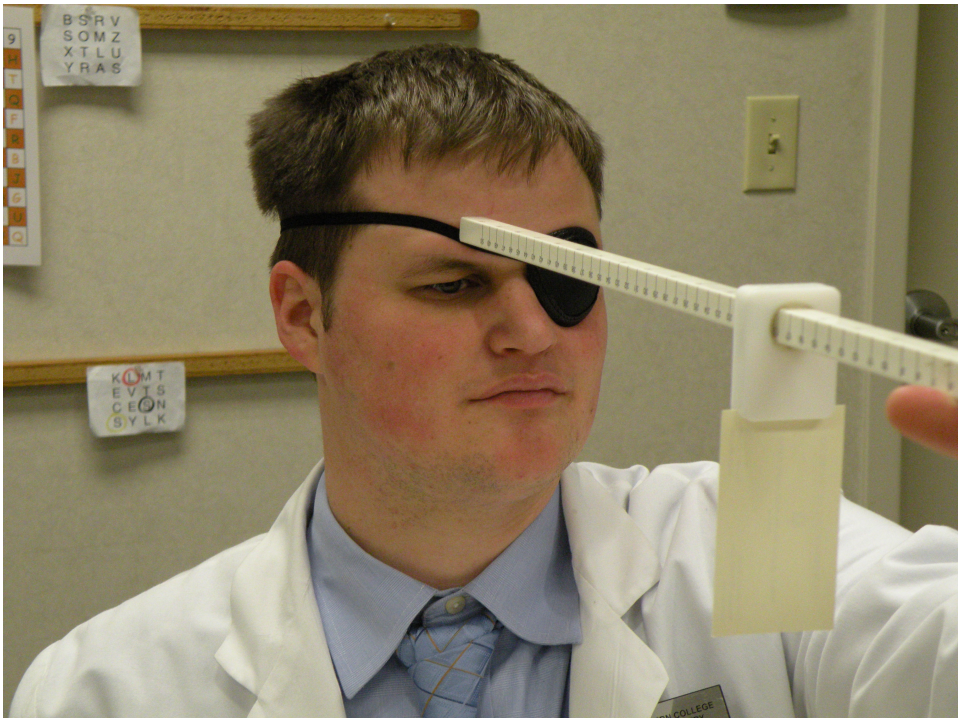
Figure 6: Push-up method demonstration

2.2.3. Minus Lens to Blur Method

For the MLB method, the same acuity target line on the same card was utilized as in the PU and PA procedures. The target was placed at 33cm. This distance was chosen so as to compensate for the effect of minification.[30] The subject wore his/her habitual corrective contact lenses if applicable. If glasses were utilized, the prescription was placed into the phoropter. Minus lenses were introduced in -0.25 D steps until the first sustained blur as reported by the subject. 2.50D was added to the result to determine the final AA.

2.2.4. Data Analysis

The median of each of the three methods was averaged and compared using a Repeated Measures One-Way Analysis of Variance **(**ANOVA), which compares three or more matched groups, based on the assumption that the differences between matched values are Gaussian.

AA was plotted graphically together with Hofstetter's equation. The difference between the three methods and those expected was made using Tukey HSD which can be used to determine the significant differences between group means in an analysis of variance setting. A 5% level of statistical significance was used.

Chapter 3. RESULTS

A one-way analysis of variance indicated that the difference between the average of the middle findings for each method and Hofstetter's expected values, found in Table 1, was statistically significant (F=44.44, d.f.=3, P<.0000). A post-hoc Tukey analysis of the entire study group demonstrated that the MLB technique varied significantly from the PU (P<0.000) and PA methods (P<0.000) as well as Hofstetter's predicted values (P<0.000). The PU (P=0.999) and PA (P=1.00) methods did not differ significantly from Hofstetter's predicted values. The PU and PA methods did not differ significantly from each other (P=1.00). (Table 2)

Table 1: Mean amplitudes ± SD

	Pull-Away	Push-Up	MLB	Hofstetter's Expected
All	13.72 D (+/- 3.88 D)	13.78 D (+/- 4.67D)	8.41 D (+/- 3.01 D)	13.80D (+/- 2.45 D)
Adults	11.71 D (+/- 1.99 D)	11.00 D (+/- 3.20 D)	7.60 D (+/- 1.72 D)	10.81 D (+/- 1.06 D)
Children	14.91 D (+/- 4.23 D)	15.42 D (+/- 4.65 D)	8.89 D (+/-3.48 D)	15.56D (+/- 0.66 D)

Table 2 Post-hoc analysis (Tukey HSD)

Group	Pull-Away vs. Push-up	Pull Away vs. MLB	Push Up vs. MLB	Pull Away vs. Hofstetter	Push Up vs. Hofstetter	MLB vs. Hofstetter
All	P=1.00	P<0.000	P<0.000	P=0.999	P =1.00	P<0.000

A Student t-test revealed that significance changed with age. Compared to Hofstetter's normative data, the PU (P=0.83) and PA (P=0.28) methods for children in this study were not

significantly different, but the opposite was found regarding the MLB ($p<0.0001$). The MLB values were also significantly different from the PU ($p<0.0001$) and PA ($p<0.0001$) values. No differences were found between the PU and PA methods ($p=0.56$). (Table 3)

Table 3 Student t-test

Group	Pull-Away vs. Push-up	Pull Away vs. MLB	Push Up vs. MLB	Pull Away vs. Hofstetter	Push Up vs. Hofstetter	MLB vs. Hofstetter
Adults	P=0.31	P<0.0001	P<0.0001	P=0.033	P=0.76	P<0.0001
Children	P=0.56	P<0.0001	P<0.0001	P=0.28	P=0.83	P<0.0001

In adults, both the PA ($p=0.033$) and MLB findings ($p<0.0001$) were significantly different from Hofstetter's expected values but the PU was not ($p=0.76$). The MLB is significantly different from the PU ($p<0.0001$) and PA ($p<0.0001$). The difference between the PU and PA methods was not significant ($p=0.31$). (Table 3)

For the entire study group, the amplitude of accommodation as measured by the PU and PA techniques underestimated accommodation as predicted by Hofstetter's equation by -0.02 D and -0.08 D respectively. The amplitude of accommodation as measured by the MLB method found in the present study underestimated accommodation by -5.44 D. (Table 4)

Table 4 Mean Difference from Hofstetter's Normative for Accommodative Amplitude

Group	Pull-Away Difference vs. Hofstetter	Push-Up Difference vs. Hofstetter	MLB Difference vs. Hofstetter
All	-.08 D	-0.02 D	-5.44 D
Adults	+0.90 D	+0.19 D	-3.21 D
Children	-0.65 D	-0.14 D	-6.67 D

The differences between the procedures and predicted results vary based upon age group. (Table 1) (Figure 7) The MLB underestimated the AA in both groups: children and adults. In children (-6.67 D), the difference was more than double that of adults (-3.21). As the age of the

patient increases, the MLB becomes more accurate, but not until the oldest subject did the predicted and actual value correspond. The PU (-0.14D) and PA (-0.65D) underestimated AA for the younger group, but overestimated the AA in the older population (PU: +0.19D, PA: +0.90D). As the age of the subject decreases, both the PU and PA become more accurate tests of AA. When comparing the PU, PA and MLB in the adult group, the PU is the most accurate method.

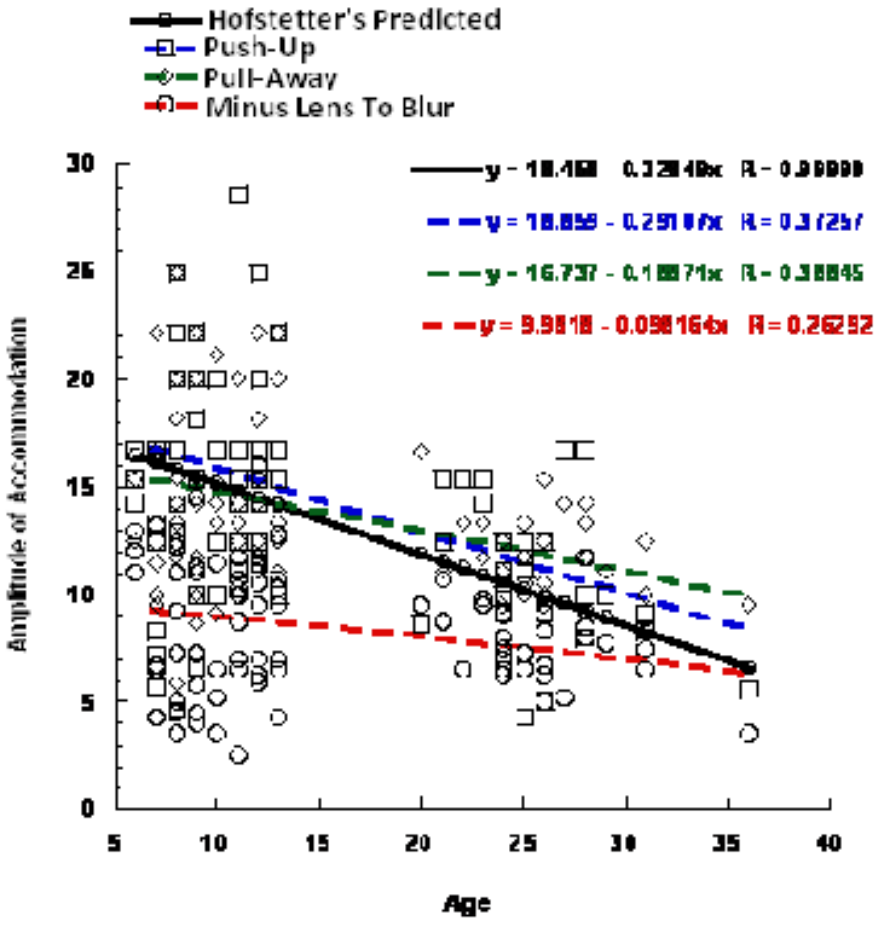

Figure 7: A comparison of the best fit line from the three techniques examined versus Hofstetter's expected values line.

Chapter 4. DISCUSSION/CONCLUSION

This study showed that the PU and PA methods to assess AA are similar to each other in children and that the MLB underestimates AA greater than previously documented. [13,24] In adults, the PU and PA techniques were similar to each other but the findings from the PA method differed when compared to Hofstetter's normative data set. The MLB method underestimated accommodation as compared to values been previously documented.[17, 19, 20]

The observation of higher values when measuring AA with the PU technique in comparison to the MLB method has been documented previously.[16, 19, 20, 24, 32] This difference has been attributed to "an enhanced, proximally-induced accommodative response as the target approaches the subject,"[33] when performing the PU method. Another explanation involves target size. As the target approaches, the angle that it subtends increases. This, in turn, delays the subject's ability to appreciate the end point, blur. With regard to the MLB technique, it has been postulated that minification of the target occurs as higher power lenses are introduced, leading to an underestimation of the true amplitude. While results from prior studies showed a difference of .5 to 2.5 D,[16,,19,20, 24, 32] the average difference between the PU/PA and MLB was over 5 D in the study reported here. This difference was largest in younger children. While the difference was smaller in adults, the difference between the test types was still significant.

An explanation for this larger than previously reported difference is most likely related to the age of the subjects studied. Hokoda and Ciuffeda[32] studied 12 subjects age 7-26 years, but only two were below the age of 10 years. The age ranges studied by Hamasaki[17] Wagstaff[19] and Sun[20] were between 42-60 years, 32-57 years and 13-58 years. In contrast, the current study had an age range of 6 to 36 years with approximately 1/3 being under the age of 10 years.

In comparing all three procedures, Rosenfield and Cohen[24] found differences among the techniques, including PU and PA. This is in contrast to Pollack[21] and Woehrle[22] and the findings reported here in regard to PU vs. PA. One possible explanation for this disparity could be the techniques used in the Rosenfield study. When performing the PU procedure, the endpoint was the first slight sustained blur. With the PA procedure, the endpoint required the subject to wait until the target was "absolutely clear." In both the Woehrle and current study, the subject had to identify the letter target at the first possible moment of clarity. If absolute clarity was required, this would, in effect, lower the amplitude since the target would be further from the subject when this occurred.

In comparing the results of the PU technique performed in the current study to the work of Donders,[1] Duane[3] and Hofstetter,[6,7] there are some differences. When contrasting the plotted curves, with the youngest subjects, both begin roughly at the same diopter amount, but the Donders curve descends at a faster rate in comparison to our study data. The oldest subject in the present study (36 years) demonstrated an approximately 6 diopter difference from Hofstetter's expected value. A similar pattern existed when comparing the findings in this thesis to Duane's normal values curve and the curve produced by the average amplitude equation put forth by Hofstetter.

The relationship to Duane's normal values curve and Hofstetter's average amplitude equation curve shows a similar pattern to each other versus the study data. In younger subjects there is a large underestimation, but both curves as well as the best fit line produced by this study intercept at or between the ages of 34 and 36 years old.

The question as to why these patterns exist in relation to Hofstetter's predictions, which are based upon the work of Duane and Donders is complex. As was described previously, the

procedure used by Duane differed significantly from what is currently used clinically. The target used in this study was a .6M letter target versus the simple black line used by Duane. The endpoint, blur, would be more difficult for children to identify, leading to the target being closer before the endpoint can be identified. This would lead to an overestimation when using lines versus letters. Duane used concave and convex lenses to help control relative magnification and thus small errors in measurement leading to large differences in amplitude found. In our PU and PA techniques, we did not introduce lenses, keeping the techniques free from minification and magnification effects of the lenses. Duane used a bracketing technique to find the "very nearest point where it (the target) begins to blur."[4] In subjects with sub-standard accommodation or those approaching presbyopia, this can cause an artificial lowering of the final result as the accommodation may decrease with each attempt to discover the final amount.

One question that many clinicians continue to have relates to the value and reliability of this type of testing in young subjects. Two studies aimed specifically to answer that question at first glance appear to have produced very different results from each other as well as with the current study. Wold[16] (n=125) and Sterner[31] (n=76) each investigated accommodation in children age 6 to 10 using a PU procedure. Wold found an average AA of 18.37 D (+/- 2.82 D) when testing only the right eye while Sterner tested both eyes individually finding 12.40 D (+/- 3.70 D) OD, 12.50 D (+/-3.70 D) OS. In comparison, data from this age group (n=33) in the present study showed an AA of 14.9 D (+/- 5.28) and are on average about 1D less than the predicted value for the same age group based on the Hofstetter equation (16.07 D). It may be that Wold overestimated AA by about 3 diopters, while Sterner underestimated it by approximately the same amount for the following reasons.

While the mean data appears dissimilar, given the standard deviation from Wold, Sterner and the current study, there is overlap among each. That being said, there the differences in the procedures may explain the differences in means. Wold investigated this specific technique along with several other binocular and monocular techniques, while Sterner investigated this procedure both binocularly and monocularly. Attention and fatigue related questions are raised especially as there is no statement in either article as to control of order of presentation of the procedures. In the current study, three methods were studied, and the order of testing was randomized, limiting the effects of both inattention and fatigue.

Wold[16] reported that he used a bracketing technique and concave lenses similar to that employed by Duane. As the letters were brought closer, the subject identified when the letters were difficult to see. This was taken as the blur point. Sterner[31] used concave lenses, as well, but chose the first sustained blur as the endpoint. In the present study, we did not utilize lenses in the PU procedure and asked the subject to report when the target first became blurry and remained that way, that is, the first sustained blur. These alternative procedures, with carefully controlled methodology, could have yielded the differences that were found between the Wold, Sterner and current study.

As shown in this study, the MLB method does, in fact, underestimate the AA as compared to Hofstetter's predicted values. This occurs in this study even after attempting to counteract the effects of minification by placing the target at 33cm as suggested by Scheiman.[30] The protocol for the MLB in this study included adding 2.50 to the result to account for working distance. As per Scheiman, even with pushing the working distance closer by 7cm, only 2.50 should be added. This is merely his suggestion and did not include a referenced study. One might question whether the results of this study would have changed if 3.00 would have been

added instead. In performing the statistical analysis with this change in parameters, we continued to find the MLB significantly different from PU, PA and Hofstetter's predicted values ($p<0.0001$). Further study should be considered to evaluate procedural changes to determine the impact on results.

This study demonstrated that certain methods are more consistent than others for measuring AA as a function of age. In children, the PU or PA methods showed the greatest correlation to Hofstetter's predicted values and MLB technique underestimated AA two times greater than was previously reported. In young adults, the MLB method underestimated AA as compared to Hofstetter's normative value. PU and PA methods overestimated AA as compared to Hofstetter's predicted values. The PU method was the most closely correlated of the three techniques. Knowing and understanding the limitations of these procedures and which is most accurate in specific populations will allow better diagnosis of accommodative and binocular dysfunction. Further investigation is warranted to determine the most accurate test in an older adult population as well as confirmation that as age increases the MLB method becomes increasingly accurate.

References

1. Donders FC,. On the Anomalies of Accommodation and Refraction of the Eye (translated by Moore WD). Boston: Milford House Inc, 1972.
2. Kaufman J. Die Absolute und Relative Accommodationsbriete in den Verschiedene Lebensaltern. Inaugural Dissertation. George Augusts Universitat, Gottingen, 1894.
3. Duane A. The accommodation and Donder's curve and the need to revising our ideas regarding them. J Am Med Assoc. 1909:52;1992-1996.
4. Duane A. Normal values of the amplitude of accommodation at all ages. J Am Med Assoc. 1912:59;1010-1013.
5. Turner M. Observations on the normal subjective amplitude of accommodation. Brit J Physiol Opt. 1958;70:70-100.
6. Hostetter HW. A comparison of Duane's and Donders' Tables of the Amplitude of Accommodation. Am J Optom and Arch Am Acad Optom. 1944;21(9):345-363.
7. Hofsteetter HW. Useful Age-Amplitude Formula. Optometric World 1950:42-45.
8. Sheard, C. The Sheard Volume: Selected Writings in Visual and Ophthalmic Optics. Philadelphia: Chilton Company, 1957.
9. Coates W. Amplitudes of accommodation in South Africa. Brit J Physiol Opt. 1955;12(2)76-81.
10. Schapero M, Nadell M. Accommodation and convergence responses in beginning and absolute presbyopes. Am J Optom. 1957;34:606-622.
11. Eames T. Accommodation in school children aged five, six, seven and eight years. Am J Ophth. 1961;51(6):1255-1257.
12. Kajiura M. Studies of presbyopia. Jap J Ophthalmol. 1965;9:85-92.
13. Kragha IKOK. Amplitude of Accommodation:Population and Methodological Differences. Ophthal Physiol Opt. 1986;6(1):75-80.
14. Beers APA, Van der Heijde GL. Age-related changes in the accommodation mechanism. Optom Vis Sci. 1996;73:235-242.
15. Sterner B, Gelleerstedt M, Sjostrom A. The amplitude of accommodation in 6-10-year-old children – not as good as expected. Ophthal Physiol Opt. 2004;24:246-251.
16. Wold RM. The spectacle amplitude of accommodation of children aged six to ten. Am J Optom Arch Am Acad Optom 1967:44;642-664.
17. Hamasaki D, Ong J, Marg E. The Amplitude of Accommodation in Presbyopia. Am J Optom and Arch Am Acad Optom. 1956;33(1):3-14.
18. Carlson NB, Kurtz D, Heath DA, et al. Clinical Procedures for the Ocular Examnation. New York: McGraw Hill, 1996.
19. Wagstaff DF. The objective measurement of the amplitude of accommodation-parts Vi and Vii. Optician. 1966;151:323-326, 431-436.
20. Sun F, Stark L, Wong NJ, et al. Changes in accommodation with age:static and dynamic. Am J Optom Physiol Opt. 1988;65:492-498.
21. Pollock J. Accommodation measurement-clear or clurred? Aust Orthopt J. 1989;25:20-22.
22. Woehrle MB, Peters RJ, Frantz KA. Accommodative Amplitude Determination: Can We Substitute the Pull-away for the Push-up Method? J Optom Vis Devel. 1997;28(4):246-249.
23. Chen AH, O'Leary DJ. Validity and repeatablility of the modified push-up method for measuring the amplitude of accommodation. Clin Exp Optom. 1998:81(2):63-71.

24. Rosenfield M, Cohen AS. Repeatebility of colinical measurement of the amplitude of accommodation. Ophthal Physiol Opt. 1996;16(3):247-249.
25.Scheiman M, Gallaway M, Coulter R, et al. Prevalence of visual anomalies and ocular pathologies in a clinic pediatric population. J. Am. Optom. Assoc. 1996;67(4): 193-201.
26. Lara F, Cacho P, Garcia A, Megias R. General binocular disorders in a clinic population. Opthalmic Physiol Opt, 2001 (1):70-74.
27. Porcar E, Martinez-Palomera A. Prevalnce of general binocular dysfunctions in a population of university students. Optom Vis Sci 1997;74(2):111-113.
28. Bartuccio M, Taub MB, Kieser J. Accommodative Insufficiency: A Literature and Case Review. Optom Vis Devel. 2008;39(1);35-40.
29. Daum KM. Accommodative insufficiency. Am J Optom Phys. 1983;60:352-359.
30. Clinical Management of Binocular Vision: Heterophoric, Accommodative, and Eye Movement Disorders; Scheiman M, Wick B; Lippincott Williams & Wilkins, 2002.
31. Sterner B, Gellerstedt M, Sjo A. Accommodative insufficiency in young school children: Ophthal. Physiol. Opt. 2006 26: 148–155.
32. Hokoda SC, Ciuffreda KJ. Measurement of accommodative in amblyopia. Ophthal Physiol Opt1982;2:205-212.
33.Rosenfield M, Gilmartin B. Effect of target proximity on the open-loop accommodative response. Optom Vis Sci 1990;67:74-79.

Appendix A: Raw data-Data in red represents that which was excluded from analysis

Patient Number	AA	PU 1	PU 2	PU 3	PA 1	PA 2	PA 3	MLB 1	MLB 2	MLB 3
1	12.2	15.38	14.29	16.67	11.11	10.53	11.11	10.75	10.75	10.75
2	12.2	12.5	12.5	12.5	10.53	11.11	11.11	8.5	9.5	8.75
3	11.3	12.5	11.76	12.5	9.09	10	9.52	8	8.25	8
4	11.3	10	10.53	11.11	6.90	7.41	7.69	6.5	6.5	6.5
5	10.7	11.76	14.29	12.5	10	9.52	10	7.75	8.25	9
6	10.4	14.29	16.67	18.18	9.09	14.29	15.38	4.75	5.25	5.25
7	11.3	11.11	11.11	11.76	10.53	9.52	9.52	7.75	7.5	7
8	11.6	14.29	14.29	16.67	11.76	11.11	12.5	9.75	9.75	10
9	9.8	9.52	11.11	10	10.53	11.11	11.11	7.5	7.75	8.25
10	10.7	13.33	12.5	12.5	10.53	11.76	10.53	9	9.25	9
11	10.7	9.09	9.09	9.52	9.52	9.52	10	6.75	6.75	6.75
12	11.9	15.38	15.38	15.38	13.33	16.67	14.29	6.5	6.5	6.5
13	11	12.5	12.5	13.33	13.33	13.33	11.76	7.25	7.5	7
14	11.3	9.09	8.70	10	11.11	13.33	12.5	6.25	6	6.5
15	7.7	5.26	5.56	5.88	9.09	9.52	10	3.5	3.5	3.75
16	11	11.76	11.76	10	11.11	11.76	11.76	6	6.75	6.5
17	10.7	5.26	5	5	11.11	14.29	12.5	5.5	4.75	5
18	10.1	8	8	8	11.76	11.76	11.76	8.5	8.5	9.5
19	11	3.64	5.13	4.26	7.14	11.11	10	6.5	6.5	6
20	9.2	9.09	8.33	7.69	12.5	13.33	11.76	7.5	7.75	7.5
21	11.3	10	10.53	11.11	10.53	11.11	11.76	8.5	7.5	7.25
22	8.27	7.69	9.09	9.52	9.09	8.33	10	6.5	5.25	6.75
23	11.3	10.53	9.52	10	10.53	12.5	12.5	8.5	9	9
24	12.5	8.70	11.76	8	16.67	18.18	16.67	9.5	9.75	9.5
25	10.1	10	9.52	11.11	12.5	13.33	13.33	8	8	8.25
26	10.1	16.67	16.67	13.33	14.29	15.38	14.29	12.25	11.75	12
27	10.7	12.5	12.5	12.5	15.38	15.38	14.29	7	6.25	6
28	11.6	16.67	15.38	14.29	13.33	14.29	12.5	9.25	9.5	9.75
29	11.3	9.09	8.33	9.52	12.5	12.5	12.5	7	7.25	7
30	11	11.11	11.76	11.11	10	10.53	10.53	7.25	7.25	7.75
32	14.9	20	25	25	14.28	13.33	16.67	10.5	11.25	12
33	15.2	14.28	14.28	14.28	12.5	12.5	14.28	10	10.25	9.75
34	14.9	14.28	15.38	15.38	18.18	16.67	18.18	11.5	12	11.5
35	14.6	15.38	15.38	13.33	13.33	13.33	14.28	10.25	10.75	10
36	15.2	14.28	14.28	15.38	12.5	14.28	13.33	8.75	8.75	9.75
37	14.6	10	10	11.11	13.33	12.5	11.76	4.75	4	4.25
38	14.9	22.22	20	20	20	18.18	20	10.5	10.25	10.25
40	14.6	14.28	16.67	16.67	20	20	20	13	12.25	12.75
41	14.9	14.28	15.38	14.28	15.38	15.38	14.28	7	6.75	7

43	14.6	22.22	22.22	22.22	20	18.18	20	9.5	9.5	9.75
44	14.6	22.22	22.22	22.22	22.22	22.22	22.22	10.5	10.75	11.5
45	14.9	12.5	14.28	12.5	10.53	13.33	11.76	10.5	10.5	10.75
46	14.6	18.18	16.67	15.38	15.38	13.33	14.28	6.5	6.5	8.25
47	15.2	12.5	12.5	12.5	14.29	12.5	11.76	6.75	6.5	6
48	15.5	16.67	16.67	16.67	13.33	14.29	14.29	11.5	11.5	11.5
49	15.5	20	20	22.22	20	21.11	22.22	5.5	5.25	5
50	15.2	16.67	13.33	15.38	13.33	14.29	20	7.25	7	7
52	14.9	20	16.67	14.29	14.29	14.29	13.33	6.25	6	6.25
53	14.9	11.11	11.76	11.11	11.76	11.11	10.52	9.25	9.5	10
54	15.5	9.56	10	10	10	9.09	9.09	3.5	3.25	3.5
55	14.9	20	20	20	20	22.22	22.22	14.75	16	16
56	15.5	12.5	10	13.33	13.33	13.33	12.5	5.5	6.5	6.75
57	15.2	10	11.11	11.11	11.11	12.5	14.29	8.5	10.75	11
58	15.2	16.67	16.67	16.67	12.5	10	9.09	2.5	2.5	2.5
59	14.9	14.29	12.5	13.33	12.5	13.33	12.5	5.5	6.5	6
60	14.6	20	16.67	22.22	11.76	11.11	11.11	7	8	6
61	16.1	20	16.67	25	25	22.22	25	4.5	4.5	4.25
62	15.8	18.18	25	25	22.22	20	22.22	12.5	14.5	14.75
64	16.4	20	16.67	22.22	22.22	20	25	12.5	13	11.5
66	16.1	16.67	16.67	16.67	13.33	12.5	14.28	12.25	12.5	12.25
67	15.9	18.18	18.18	16.67	18.18	20	20	5.5	6	5.75
68	16.1	20	20	20	16.67	20	22.22	8.25	9.25	9.75
69	16.1	25	25	25	16.67	18.18	20	11.75	13	13.25
70	16.1	22.22	22.22	25	16.67	18.18	20	11	11.25	11
71	15.9	20	20	20	12.5	11.76	11.11	5.75	7.25	7.5
72	16.4	11.11	13.33	13.33	9.52	9.52	10.53	6.75	6.75	6.75
73	15.9	10	8.33	9.9	8	13.33	8.7	4	4	4.25
74	15.9	22.22	22.22	22.22	15.38	15.38	15.38	11	11	10.5
75	16.1	16.67	16.67	5.5	18.18	15.38	15.38	12.5	12.5	12.75
76	16.5	16.67	15.38	15.38	15.38	15.38	15.38	13	13	13.5
77	16.5	16.67	16.67	15.38	14.29	15.38	16.67	11	11.5	11
78	16.4	12.5	12.5	12.5	9.09	11.11	10	7	6.5	6.5
79	16.1	16.67	16.67	15.38	12.5	11.76	11.11	7	7.25	7.5
80	16.4	8.33	7.69	8.33	10.5	12	11.5	4.5	4	4.25
81	16.1	14.29	14.29	14.29	14.29	14.29	14.29	4.75	5	5
83	16.5	13.33	14.29	15.38	12.5	12.5	12.5	11	12.25	12
84	16.1	5	4.54	4.17	6.35	5.88	6.66	3.5	3.5	3.5
85	15.9	14.29	15.38	16.67	15.38	14.29	13.33	11.25	11.25	11
86	15.9	7.14	5.88	6.66	10	10	10	4.5	4.5	4
87	16.4	5.71	6.25	5.71	18.18	20	16.67	13	13.25	13.25

88	16.4	7.14	6.25	14	16.67	18.18	16.67	16.75	16.25	15.25
89	16.5	33.33	50	25	20	20	20	20.75	21	20.75
63	16.4	33.33	33.33	50	20	25	25	10	10.25	10.5
51	14.6	28.57	28.57	28.57	22.22	25	22.22	12.25	13.25	13
39	15.2	28.57	28.57	33.33	22.22	33.33	16.67	13	13.25	13.5
31	14.6	25	25	28.57	18.18	16.67	16.67	11.5	12.25	12
82	16.4	28.57	20	25	14.29	16.67	11.11	5	6.25	6
65	15.5	6.67	6.67	5.71	33.33	25	25	5	5	4.5
90	15.5	25	16.67	20	33.33	25	33.33	10	12	11.75
42	15.2	33	50	50	18.18	20	20	11.5	11.75	12.5