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Clinical Amplitude of Accommodation in Children between 5 and 10 Years of Age

Jaclyn A. Benzoni OD, MS, FAAO; Mark Rosenfield MCOptom, PhD, FAAO

ABSTRACT

Background: While there have been extensive studies of the amplitude of accommodation (AA) in adults, estimates of AA from studies in children between 5 and 10 years of age vary widely with some of the data being contradictory. Further, since values of AA are used for the diagnosis of several conditions including accommodative insufficiency (AI), it is important to able to compare clinical findings with age-defined norms.

Methods: The present study was performed on 60 asymptomatic children between 5 and 10 years of age. Each child was refracted for distance viewing, and both push-up (PU) and push-down (PD) amplitudes were recorded monocularly using a Royal Air Force (RAF) nearpoint rule. Four readings (2 PU and 2 PD) were taken on each subject. The same procedures were also carried out on 38 adult subjects between 20 and 50 years of age.

Results: The mean findings (average of PU and PD) declined from 16.2D (SEM=1.7D) at 5 years of age to 12.4D (SEM=1.4D) at 10 years of age. A two-phase regression was observed, with a rapid decline between 5 and 7 years of age, but minimal change between 7 and 10 years of age.

Conclusions: Both the pediatric and adult data is broadly similar to the classic findings of Donders and Duane. However, a relatively high percentage (36%) of children met the most commonly adopted criterion for AI, suggesting that this standard may need to be reexamined in this particular age group.

Keywords: Accommodation, accommodative amplitude, accommodative insufficiency, pediatric vision care

Although determination of the amplitude of accommodation (AA) is a standard clinical procedure,[1] previous measurements in patients between 5 and 10 years of age have produced contradictory findings. This is an extremely important period in a child's development, and focusing difficulties during this time could impair educational progress. While the classic findings of Donders[2] and Duane[3,4] are well established as normative values for AA in adults, there are potential flaws in applying them to a pediatric population. For example, Donders did not test any subjects less than 10 years of age. While values for a younger population can be extrapolated from the adult data, it is not clear whether such extrapolation is valid.

Additionally, while Duane examined nearly 1500 subjects between 8 and 72 years of age, only 33 were between 8 and 12 years old. Further, a range of AA between 11 and 17.5D was found in this particular age range, and no subjects under 8 were tested. Based on the findings of Donders and Duane, Hofstetter[5] devised a series of equations to predict the minimum, probable and maximum AA as a function of age. Although these are based almost exclusively on findings in adults, they have been proposed for making clinical diagnoses in children. For example, accommodative insufficiency (AI) is a condition where the patient has difficulty stimulating

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Benzoni JA, Rosenfield M. Clinical Amplitude of Accommodation in Children Between 5 and 10 Years of Age. Optom Vis Dev 2012;43(3):109-114

accommodation. The characteristic finding is an AA below the lower limit of the expected value for the patient's age.[6] The most widely used criterion for AI uses Hofstetter's formula for the minimum amplitude [i.e., 15-(0.25*age in years)], and an abnormality is considered to exist when the AA is 2 or more diopters below this value.[7] However, Cacho et al.[8] listed 8 alternative standards for AI. Of the various accommodative problems, AI is the most prevalent.[7] It is unclear whether the use of predominately adult data is valid for defining the condition in children. Since AI can produce significant symptoms during near work, proper diagnosis based upon appropriate normative findings is essential.

While a number of previous studies have measured the AA in younger children, the findings vary widely, and are in some cases contradictory. For example, Eames[9] measured the AA in 899 children between 5 and 8 years of age. A push-up technique was used with the smallest print each child could make out, and a decrease in accommodation was found with increasing age. The AA decreased from 14.3D in 5 year old children to 12.7D in the 7 year olds. Interestingly, Eames compared the AA in suburban and urban children, and reported that the mean values of the urban children averaged 5.1D less than those of the suburban individuals. He speculated that this may be due to the poorer environment, malnutrition and weaker physical development in the urban community.

In contrast, in a study of 125 first, second and third grade children, Wold[10] observed that the AA was either relatively stable, or increased between 7 and 9 years of age. Wold hypothesized that the AA curve as a function of age may be sigmoid in shape, with level areas both between the ages of seven and nine and beyond the age of about fifty-two years. A total of 5 different objective and subjective techniques were used to quantify the AA in this particular investigation, and only one (dynamic retinoscopy) showed a decline in AA with age. Later, Woodruff[11] measured AA in 286 children between 3 and 11 years old, and found an increase in AA with age in this population. A subjective procedure was used whereby a -10.00 lens was introduced monocularly while viewing a detailed 20/30 target at 33 cm. If the target was correctly identified by the child, additional -2.00 lenses were added. Once the target could not be distinguished, the minus power was reduced in -0.25 steps until the target was seen correctly 5 out of 6 times. Using this technique, the mean AA increased from 10.72D (SEM = ±0.21) at age 5 to 13.7D (SEM = ±0.40) at 10 years of age. More recently, Chen et al.[12] observed a decrease in accommodation for children between 1 and 17 years of age (N=405). A "modified push up method" was used which is effectively a push-down procedure.[1] A blurred target was moved away from the subject until they were just able to see it clearly. The authors found a more rapid decrease than would be predicted based on Duane's data. Using linear regression, Chen et al. proposed the following equation to approximate amplitude: -0.52(age) + 16.58.

Other investigators have used objective techniques to assess the AA. These may have significant advantages when examining children, since they eliminate the need for the subjective assessment of blur. For example, Jimenez et al.[13] tested 1056 subjects between 6 and 12 years of age using modified dynamic retinoscopy. Jimenez also observed a decrease in AA as a function of age in this population, which could be described by the equation: AA = -0.40(age) + 16.16. Further, Anderson et al.[14] used an open-field, infra-red optometer to measure AA in subjects between 3 and 40 years of age. The target was positioned at a viewing distance of 33cm, and minus lenses introduced to increase the accommodative stimulus. The authors observed that AA declined in a curvilinear manner with increasing age. The predicted values for 3, 5, 7 and 15 year olds were 7.08, 7.07, 7.05 and 7.00D, respectively, indicting no significant change within this age range. A recent study compared the repeatability of both dynamic retinoscopy and subjective measurements of the AA in young adults (18-30 years of age) and concluded that dynamic retinoscopy had higher reproducibility and avoided overestimation from the depth-of-field of the eye.[15]

However, objective assessment of the AA is less commonly performed in the clinical setting, when compared with subjective determination. Given that having normative data for AA as a function of age in 5-10 year old children is critical for the diagnosis and treatment of accommodative anomalies, this study compared subjective measurements of AA as a function of age, and to the results of previously cited findings.

Methods

Sixty asymptomatic children between 5 and 10 years of age were utilized in this study. All were pediatric patients presenting for routine eye care at the

Table 1: Mean AA (average of PU and PD) as a function of age.

Age (years)	N	Mean (D)	SEM (D)
5	6	16.2	1.7
6	14	14.0	0.8
7	10	10.9	0.8
8	12	12.2	1.0
9	9	12.3	1.0
10	9	12.4	1.4

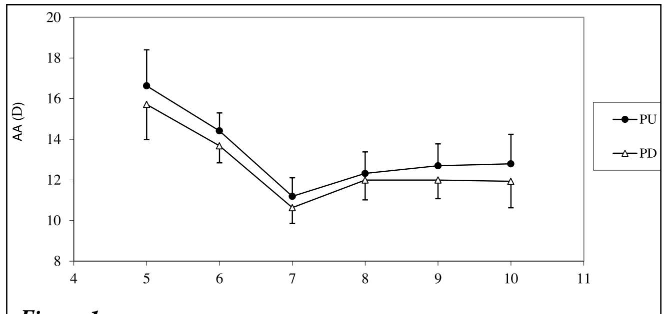

Figure 1: Amplitude of accommodation (AA) in diopters as a function of age when measured using the push-up (PU) and push-down (PD) procedures in 60 subjects between 5 and 10 years of age. Error bars indicate 1 SEM.s

SUNY College of Optometry. After a full refractive examination, all had corrected visual acuity of at least 6/6 (20/20) in each eye, and none had strabismus or manifest ocular disease. The study followed the tenets of the Declaration of Helsinki, and informed consent was obtained from the parents or guardians of the subjects after an explanation of the nature and possible consequences of the study. The testing protocol was approved by the Institutional Review Board (IRB) at the SUNY College of Optometry.

Each subject received a comprehensive eye examination, including measurement of manifest distance refractive error without cycloplegia. This refractive correction was worn by the subject in a trial frame over their right eye. As the dioptric scale becomes compressed as the target is advanced towards the subject, an additional -5.00D sphere was added to the refractive correction to move the near point away from the subject, thereby enlarging the linear space between diopter markings and increasing the precision of the measurements. The left eye was occluded during the trial with an elasticated black eye patch. A detailed picture of a birthday cake measuring 3.5cm wide by 2.0cm high was used as a target. Further details were added to the picture including the words, "Happy Birthday" printed with letters approximately 0.5mm high, and other small features were added to promote an awareness of detail and fine print. The target was mounted on an RAF near point rule.

A total of four measurements were made for each subject (2 each using the push-up and push-down techniques[1]). When performing the push-up (PU) procedure, as the object was advanced toward the subject, they were asked to report when the small detail first appeared "fuzzy." Specific details on the target were pointed out to ensure that the child was actually seeing them. Once the subject reported that they could no longer see the fine detail, they were encouraged to try and "clear it up" in an attempt to achieve the maximum accommodative response. When the point of first slight sustained blur was reached, the dioptric value of this target position was recorded as their near point of accommodation (adding in the additional 5.0D from the supplementary minus lens). In performing the push-down (PD) procedure, the object was placed initially at a position closer than the subject's near point of accommodation so that it appeared blurry, and then moved away from the subject until they reported that it "just became clear again." The four measurements were taken in a fixed order, i.e., PU, PD, PU and then PD. In all cases, testing was undertaken by the principal author (JAB) who moved the target herself, and the subjects were not allowed to touch the target. All statistical analyses were performed using StatistiXL software (StatistiXL, Broadway – Nedlands, Western Australia) on a Dell Optiplex GX280 computer (Dell Corporation, Round Rock, TX).In addition, the AA was measured using the same procedure in 38 adult subjects; 20 of whom were between 20 and 29 years of age, while the remaining 18 subjects were between 30 and 50 years of age.

Results

The mean values for both the PU and PD AA as a function of age are shown in Figure 1. A repeated measures analysis of variance indicated that the PU findings were significantly higher than the PD results ($F=23.96$; $df = 1, 54$; $p <0.001$). This is consistent with previous reports.[1,16] However, because similar trends were observed for both procedures with age, and as the PU and PD techniques probably over- and underestimate the subjective AA, respectively, due to the subject's reaction time,[1] all subsequent analyses were performed using an average of the PU and PD measurements. The mean values of AA as a function of age are shown in Table 1, while findings for each

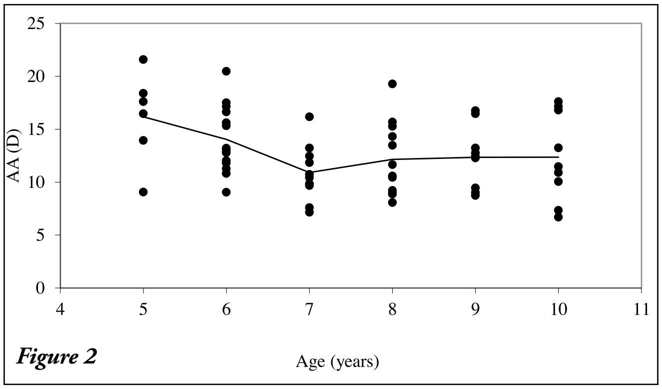

Figure 2: *Individual values of amplitude of accommodation (AA) in diopters as a function of age for 60 subjects between 5 and 10 years of age. The solid line indicates the mean of the PU and PD findings.*

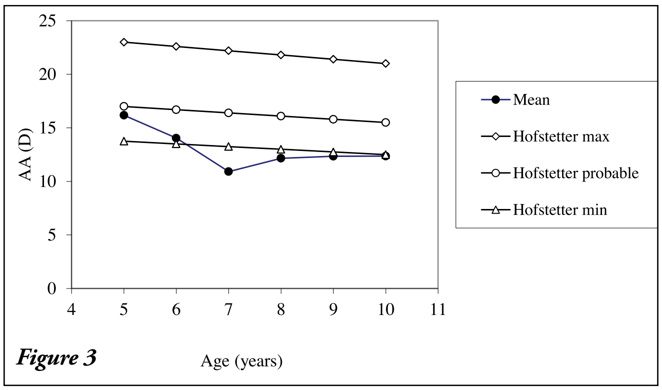

Figure 3: *Mean findings from the present study for 60 subjects between 5 and 10 years of age compared with the minimum, probable and maximum AA as a function of age predicted by Hofstetter's equations.*[5]

individual subject are illustrated in Figure 2. The change in AA with age across the whole age range tested (5-10 years) narrowly failed to reach statistical significance (F=23.22; df= 5,54; p=0.055). However, the change in AA between 5 and 7 years of age was significant (F=5.38; df=2,27, p=0.011). Post-hoc testing using the Tukey test indicated that the mean AA for the 5 year old group was significantly different from those found for the 7, 8, 9 and 10 year olds (p<0.003 in all cases) while the mean values for the 6 and 7 year old groups were also significantly different (p=0.002). None of the other comparisons between the various age groups were significant.

Figures 1 and 2 show a two-phase change in AA with age. Between 5-7 years of age, there was a rapid decline which is best fit by the linear regression equation y = -2.69x + 29.93 (r = 0.529; p=0.003). However, between 8 and 10 years of age, minimal change in the mean amplitude was observed (r=0.04; p=0.86). When considering the data in its entirety from 5 to 10 years old, the linear regression function was y = -0.58x + 17.19. (r = 0.258; p=0.047).

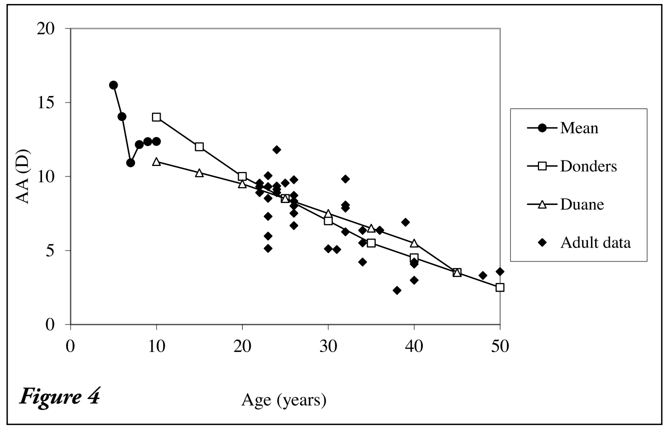

Figure 4: *Mean findings from the present study for 60 subjects between 5 and 10 years of age and 38 subjects between 20 and 50 years of age (adult data) compared with results from the classic studies of Donders*[2] *and Duane.*[3]

Data from the present study were compared with the values predicted by Hofstetter's equations[5] as illustrated in Figure 3. It is evident that the mean AAs found in the present study lie close to (or in many cases below) the minimum expected values extrapolated by Hofstetter. Additionally, the findings of the present investigation were compared with results from the classic studies of Donders[2] and Duane.[3] These results, together with the 38 adult subjects tested here are shown in Figure 4. The measured values for children between 8 and 10 years of age lay approximately midway between Donders' and Duane's findings, and appear to provide a smooth transition into the adult data. The adult data from the present study are very similar to those obtained by both Donders and Duane.

Discussion

In the present investigation, the mean AA (average of PU and PD procedures) declined from 16.2D at 5 years of age to 12.4D at 10 years of age. Linear regression analysis showed a decline of 0.58D per year. However, this may not be an accurate assessment due to the 2-stage regression of AA shown in Figs 1 and 2, with the rate of decline being much faster between 5 and 7 years of age. Other studies have also suggested that the rate of change of AA may be non-linear. For example, both Wold[10] and Anderson et al.[14] indicated that a sigmoidal function may be more appropriate. Indeed, the pattern of change observed in the present study with a decline between 5 and 7 years of age, followed by either no significant change or a slight increase between 7 and 10 years of age is consistent with the observations of Wold. A summary of the

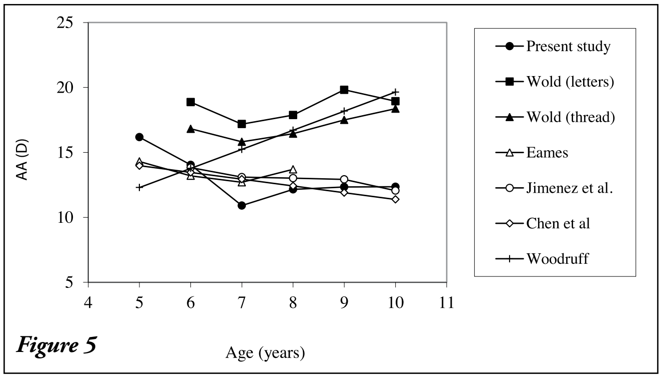

Figure 5: Mean findings from the present study compared with the results of Wold[10], Eames[9], Jimenez et al.[13], Chen et al.[12], and Woodruff[11]. Although Wold[10] used a total of 5 objective and subjective methods of measurement, only results for the two techniques most similar to the procedures adopted here, i.e., letters or two fine threads are shown here.

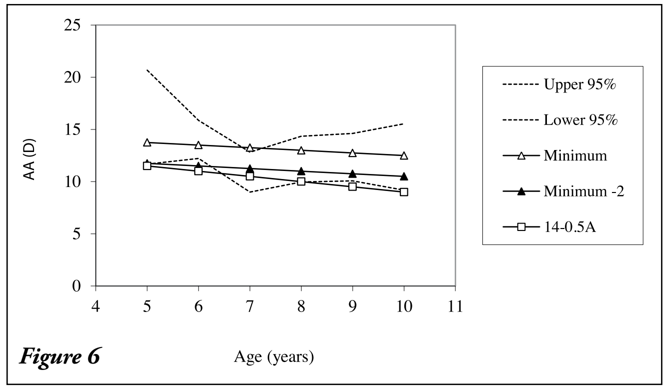

*Figure 6: The two dashed lines represent the upper and lower 95% confidence limits for the findings of the present study. The open and closed triangles illustrate the predicted values based on Hofstetter's minimum expected finding (15-0.25*age) and the AI criterion of 2D below this minimum value, respectively. It is apparent that both the minimum expected finding and the commonly-used AI criterion (2D below this minimum value) lie within the 95% limit. However, since the lower boundary of the 95% limits can be closely approximated by the equation 14-0.50*age in years, this may provide a better standard for AI.*

findings reported both in the present study and by Wold[10], Eames[9], Jiménez et al.[13], Chen et al.[12] and Woodruff[11] is shown in Figure 5.

It should be noted that the results presented here are lower than those recorded by Wold.[10] Different endpoint criteria were used, making direct comparison difficult. Although Wold used a total of 5 objective and subjective methods of measurement, for the two techniques most similar to the procedures adopted here, subjects either viewed "letters on the bottom line of the card" (the exact size was not specified) or two fine threads, each of which was 0.2mm wide and separated by 0.2mm. In the case of the letters, subjects were asked to report when they "had trouble seeing the letters." In the case of the threads, subjects were asked to report when "the threads appeared as a single blurred thread." It is likely that both of these thresholds went beyond the "first slight sustained blur" endpoint adopted in the present study. This would cause the AA to be overestimated.

Measurement of the amplitude of accommodation is an important clinical procedure in children. Diagnosis of several clinical conditions, including AI may be based on this parameter. Examination of Figure 3 indicates that many of the children tested here fell below Hofstetter's minimum amplitude (15-0.25*age in years). One possibility is that Hofstetter's formulae are inappropriate for assessing the AA in children as they are extrapolated from Donders' and Duane's data[2,3] which was obtained, almost exclusively, from subjects over 10 years of age. Alternatively, the incidence of accommodative anomalies may be higher than reported previously. Indeed, Sterner et al.[17] used a PU procedure to measure AA in 76 children between 6 and 10 years of age and observed that approximately 54% of their subjects had amplitudes at least 0.50D lower than Hofstetter's minimum expected value, while 34% met the criterion of 2D below this minimum finding. This finding is very similar to our results, with 36% of the subjects tested having an AA that fell more than 2D below Hofstetter's minimum value. It should be noted that the population studied by Sterner et al. was randomly selected from junior schools, rather than being drawn from a clinic population as was the case in the present investigation. Interestingly, if an objective technique such as dynamic retinoscopy was used to measure AA, one might predict lower findings, as has been shown in adults,[15] which would increase the prevalence of AI.

Accordingly, it seems that the criterion for AI should be re-examined in 5-10 year old children on the basis of data obtained specifically from this age group. Figure 6 shows the upper and lower 95% confidence limits for the findings of the present study, as well as the predicted values based on Hofstetter's minimum expected finding and the AI criterion of 2D below this minimum value. It is apparent that both the minimum predicted finding and 2D below this value lie within this 95% limit. However, the lower boundary of the 95% limits can be approximated by the equation 14-0.50*age in years. We suggest that further research be undertaken in a larger sample of subjects to determine whether this is a better criterion for AI.

The findings of the present study indicate that AA declines rapidly between 5 and 7 years of age with only minimal change between 7 and 10 years of age. Nevertheless, the findings are broadly similar to those predicted by Donders' and Duane's curves. However, the results are lower than would be predicted by Hofstetter's equations for AA as a function of age, and accordingly, it is questionable whether these equations, which were extrapolated from adult data, should be used for diagnosing clinical conditions such as AI in children.

Conflict of Interest: The authors have no financial interest in any of the equipment used in the present study.

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COVD 2012 Research Grant Winners

Three Research Grants were awarded in June 2012. All three Grants received $4,000.00 each.

Chris Chase, PhD, FAAO

Western University of Health Sciences

Co-Investigators: Maureen Powers, PhD, FCOVD, FAAO, FARVO – Gemstone Foundation Research Institute; Chunming Liu, PhD, MD, OD – Western University of Health Sciences; Efrain Castellanos, OD, FCOVD – Western University of Health Sciences

Project Title:
"Studying the Role of Accommodative – Vergence Function in Reading Development Through Visual Screening"

Kenneth J. Ciuffreda, OD, PhD, FAAO, FARVO, FCOVD-A

SUNY – State College of Optometry, Department of Biological and Vision Sciences

Co –Investigator: Preethi Thiagarajan, BS Optom, MS, FAAO - SUNY – State College of Optometry

Project Title:
"Treatment of TBI-Induced Oculomotor Dysfunction and Associated Reading Problems"

Mitchell Scheiman, OD, FCOVD

Co-Investigators: Mark Mintz, MD – Center for Neurological and Neurodevelopmental Health; Eric Borsting, OD, FCOVD; Barry Tannen, OD, FCOVD, FAAO; Michael Gallaway, OD, FCOVD

Project Title:
"Convergence Insufficiency and its Relationship to ADHD"