Minus-Lens–Stimulated Accommodative Amplitude Decreases Sigmoidally with Age: A Study of Objectively Measured Accommodative Amplitudes from Age 3

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Purpose. Guidelines for predicting accommodative amplitude by age are often based on subjective push-up test data that overestimate the accommodative response. Studies in which objective measurements were used have defined expected amplitudes for adults, but expected amplitudes for children remain unknown. In this study, objective methods were used to measure accommodative amplitude in a wide age range of individuals, to define the relationship of amplitude and age from age 3.

Methods. Accommodative responses were measured in 140 subjects aged 3 to 40 years. Measurements were taken with the Grand Seiko autorefractor (RyuSyo Industrial Co., Ltd., Kagawa, Japan) as the subjects viewed a high-contrast target at 33 cm through minus lenses of increasing power until the responses showed no further increase in accommodation.

Results. The maximum accommodative amplitude of each subject was plotted by age, and a curvilinear function fit to the data: $y = 7.33 - 0.0035(\text{age} - 3)^2$ ($P < 0.001$). Tangent analysis of the fit indicated that the accommodative amplitude remained relatively stable until age 20. Data from this study were then pooled with objective amplitudes from previous studies of adults up to age 70. A sigmoidal function was fit to the data: $y = 7.083/(1 + e^{[0.2031(\text{age}-36.2)-0.6109]})$ ($P < 0.001$). The sigmoidal function indicated relatively stable amplitudes below age 20 years, a rapid linear decline between 20 and 50 years, and a taper to 0 beyond 50 years.

Conclusions. These data indicate that accommodative amplitude decreases in a curvilinear manner from 3 to 40 years. When combined with data from previous studies, a sigmoidal function describes the overall trend throughout life with the biggest decrease occurring between 20 and 50 years. (*Invest Ophthalmol Vis Sci.* 2008;49:2919–2926) DOI:10.1167/iovs.07-1492

Investigations of changes in maximum accommodative amplitude with age date back to the late 1800s, with studies performed by Donder[1] who measured accommodation in 130 individuals between the ages of 10 and 80 years, using a variation of the subjective push-up technique in which a target made from a set of vertical wires was moved closer to the subject until the subjects indicated blur. In the early 1900s, Duane[2–4] contributed his own studies measuring maximum accommodative amplitude in more than 4200 eyes of individuals aged 8 to 72 with a technique similar to Donder's, in which a thin vertical line drawn on a card was moved closer to the subject until the subject indicated blur. These data were later compiled by Hofstetter[5] who attempted to reconcile the differences between the two data sets, and potentially combine them into one complete set describing changes in accommodative amplitude with age. Hofstetter's overall conclusion was that although the data were in agreement between the ages of 20 to 40 years, overall the data did not "justify the use of any specific curve to represent the trend of the amplitude with age." However, for clinical purposes, Hofstetter approximated a linear fit to all the combined data (age range, 8–80 years) so that clinicians would have an estimate of what the norms should be for each age group.

Although simple to calculate, one must use caution when applying the Hofstetter[5] linear equation of accommodative amplitude. Aside from being a rough approximation, when using the equation to estimate accommodative amplitude in individuals younger than 8 years of age, one is making the assumption that accommodation increases linearly with decreasing age, but the original data set was restricted to those 8 years of age and older, and so these values are an extrapolation beyond the data set. One must also be careful not to interpret the predicted values from Hofstetter's equation as the true accommodative amplitude, as the endpoint of the subjective push-up test includes the depth of field, which will overestimate the response. The subjective push-up test on which the Hofstetter equation is based is similarly subject to shortcomings. Large dioptric errors can occur when taking measurements at close working distances, because the dioptric scale compresses as the target is moved closer, and the delay in time for which subjects may report an initial blur of the target as the target is moved progressively closer can overestimate the response amplitude, especially in young children who may not comprehend the concept of the first blur endpoint, or for clinicians who move the target too rapidly.

During the 1960s, Eames et al.[6] and Wold[7] independently conducted studies in which they used a variety of subjective methods for measuring accommodative amplitude on a large number of school-aged children in an effort to describe amplitude function by age in the youngest subjects. Although the subjective measurements of Eames showed a trend of decreasing amplitude between ages 5 and 8 years, the subjective measurements from Wold's study indicated stable amplitudes of accommodation in subjects between the ages of 6 and 10 years. These findings led Wold to believe a sigmoid function may better describe amplitude changes by age, while Eames upheld the Hofstetter linear description of amplitude change by age.[6,7]

More recently, investigators have used objective measurements of accommodation to identify a more precise picture of how amplitude changes with age in several studies.[8–11] These

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studies provided a thorough understanding of accommodative amplitude changes at older ages; however, they did not include amplitudes in younger individuals, to provide a complete picture of accommodative amplitude from early youth.

The purpose of this study was to measure the accommodative amplitude objectively over a wide range of ages to investigate the trend of amplitude change with age and determine whether accommodative amplitude declines in a linear fashion, as suggested by the work of Hofstetter,[5] or if accommodative amplitude declines in a sigmoidal fashion, as suggested by Wold.[7]

Methods

The study adhered to the tenets of the Declaration of Helsinki and was approved by the university committee for the protection of human subjects. Informed consent was obtained from all adult participants, and parental consent and the child's assent was obtained for all participants less than 18 years of age.

The 140 individuals who participated in the study were recruited from the University Eye Institute's staff, student, and patient populations. Subjects included 81 females and 59 males ranging in age from 3 to 40 years. For recruitment, subjects were binned in age groups from 3 to 5 years and then in 5-year age intervals from 6 to 40 years. Each age bin had at least 15 participants.

Subjects were excluded from participation if they had a history of significant eye or head injuries, had undergone intraocular surgery, or were currently using any medications that are suspected of interfering with accommodation. In addition, subjects with a history of strabismus or amblyopia were excluded from participation in the study. A small number of young subjects aged 3 to 5 years who were recruited for the study were unable to participate, due to their unwillingness to place their chins on the chinrest for the measurements. No data were collected from these individuals.

Subjects with refractive error wore their habitual corrections (spectacles or contact lenses) for all study measurements. Study participants included 65 myopic persons (>−0.50 DS), 3 hyperopic persons (>+0.75 DS), 68 emmetropic persons, and 4 mixed astigmatic persons. Five adult subjects had undergone LASIK refractive surgery and were classified as myopic persons according to their presurgical refractive status.

Distance visual acuities were measured on all subjects by using an age-appropriate acuity task: either the Bailey-Lovie high-contrast acuity chart[12] for older subjects or the Lea symbols acuity-matching test[13] for younger subjects. All subjects had monocular visual acuities of 20/20 in each eye, except for a few of the youngest subjects who were testable only to 20/25. This level of acuity is within the expected range for normal young children.[14,15]

Refraction of the eye was measured with the Grand Seiko WR-5100K open-field Autorefractor (RyuSyo Industrial Co., Ltd. Kagawa, Japan). All measurements were taken on the subject's left eye with the right eye occluded while the subject wore refractive correction if he or she had one. The subjects were first instructed to view a high-contrast target with pictures and letters positioned 11 m across the room and a series of repeated distance measurements was taken over a period of seconds. The mean of these distance measurements represented the subjects' distance corrected refraction.

Next, a high-contrast target with both letters and pictures was suspended from the near-point rod of the autorefractor at the 3-D position (33.33 cm). The letters on the target ranged in size from 0.8 to 2.4 mm (~20/32 to 20/100 Snellen equivalent at a 33-cm viewing distance), whereas the overall size of the pictures was 13 mm and included multiple fine detail components as small as 0.8 mm. The subjects were instructed to look at the target and keep it clear (in focus) while repeated measurements were taken over a series of seconds. For preschool-age subjects, attention was directed to small details of the target and questions about the target were asked to engage the young children in focusing on the target. The mean of these measurements represented the accommodative response to the 3-D target demand. Accommodative demand was then increased sequentially in 1-D steps by an examiner holding minus lenses in the spectacle plane (13 mm) of the viewing eye of the subject. For subjects wearing glasses, the trial lens was held in front of and touching the spectacle lens. For each minus lens, repeated measurements were taken through the lens to determine the mean accommodative lag to each demand which was then used to calculate the mean accommodative response. The power of the minus lens was increased for each subject until the measurements reflected no additional increase in total accommodative response.

The autorefractor was set to output both the spherical and cylindrical components of the refraction. For data analysis, all measurements were converted to the spherical equivalent (one half the cylinder power added to the spherical power). In addition, both the demand and the response measurements had to be adjusted for the addition of the minus lenses in all subjects, as well as the presence of spectacles lenses for those subjects wearing them. All demand and response values were referenced to the corneal plane using the effectivity formula presented by Mutti et al.[16] for reconciling the effect of spectacle lenses on autorefractor readings.

Stimulus demands (SD) were determined by

$$\mathrm{SD} = \left\{ \frac{1}{\left[\dfrac{1}{\left(\dfrac{1}{(0.013 - \mathrm{DTE})} \right) + \text{Lens Power}} \right] - 0.013} \right\} - \mathrm{REcornea} \qquad (1)$$

Autorefractor responses (AR) were determined by

$$\mathrm{AR} = \left(\frac{1}{\left\{ \dfrac{1}{\left[\dfrac{1}{\left(\dfrac{1}{\mathrm{RawAR}} \right) + 0.013} \right] + \text{Lens Power}} \right\} - 0.013} \right) - \mathrm{REcornea} \qquad (2)$$

In these formulas, 0.013 is the vertex distance in meters of lenses placed in front of the eye, DTE is the distance in meters of the target to the eye, Lens Power is the total power of any lenses placed in front of the eye (added minus lenses to stimulate accommodation and spherical equivalent of spectacle lenses if present), REcornea is the refractive error at the corneal plane, and RawAR is the spherical equivalent of the autorefractor output set for the corneal plane.

For each subject, accommodative responses were plotted as a function of stimulus demand and evaluated to determine the maximum accommodative response for each subject. The plots for each subject showed increasing accommodation with increasing demand until the subject could no longer exert any more accommodation. At this point the response would either peak and drop off, or plateau for subsequent increases in demand (Fig. 1). The maximum response was identified and adjusted by the distance autorefractor measurement for each subject and termed the maximum accommodative amplitude for the subject.

An alternative technique for stimulating accommodation is by introducing proximal blur by moving a near target progressively closer to the subject. In the present study, physical limitations due to the presence of the instrument beam splitter of the Grand Seiko autorefractor prevented the near target from being positioned closer than 12.5 cm from the subject (8-D demand). Although this demand may be sufficient to elicit maximum amplitudes in adult subjects, for the young subjects, an 8-D demand may not be sufficient. However, to compare

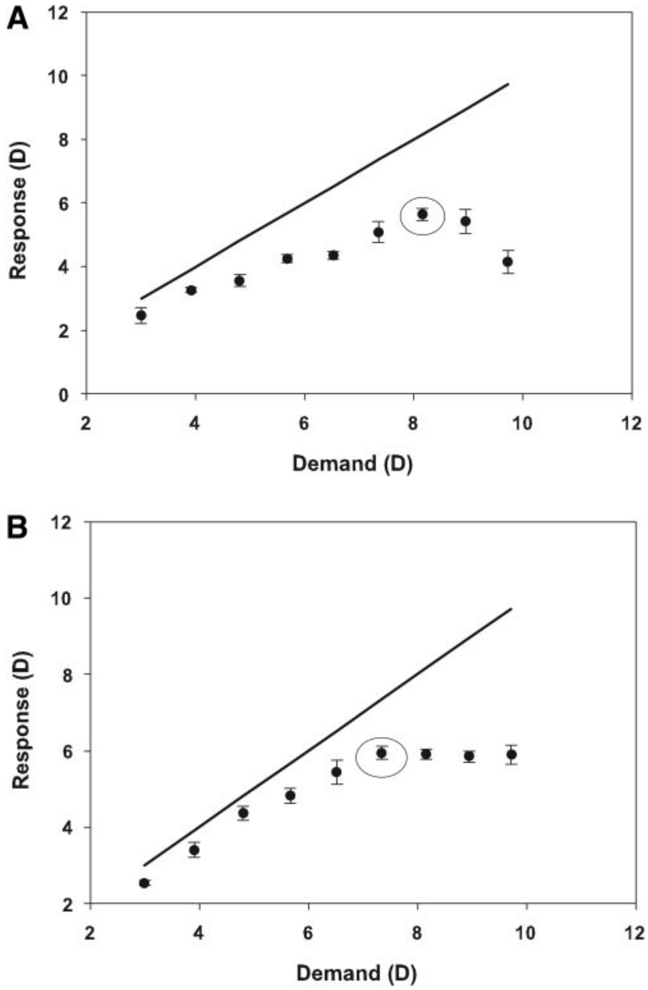

FIGURE 1. Examples of accommodative stimulus response functions for two subjects. *Solid line*: 1:1 stimulus/demand line; (●) represent the subject's accommodative response. In each plot, the *circle* represents the point of maximum accommodative response. (**A**) A 17-year-old subject whose response peaked and declined with increasing demand. (**B**) A 19-year-old subject whose response peaked and plateaued.

potential differences in adult responses to minus lens blur versus proximal stimuli, additional measurements were taken on a small subset of adult subjects from the primary study sample. The subset included 22 subjects between the ages of 23 to 40 years who had amplitudes of accommodation less than 6.5 D when measured with the standard minus lens induced blur technique. These subjects then had measurements taken with the autorefractor while viewing the same target at increasingly near positions of 3-, 4-, 5-, 6-, 7-, and 8-D demands. For all subjects, the accommodative response to the proximal blur peaked or reached a plateau by the 8-D demand, and thus it was possible to determine a maximum amplitude. The amplitudes measured with minus-lens–induced blur were then compared with the amplitudes measured from proximal-induced blur.

Data Analysis

Amplitudes for all subjects were plotted as a function of age, and curvilinear regression analysis was used to describe the change in accommodative amplitude with increasing age. In addition curvilinear regression fits to myopic and emmetropic subjects' data were compared, to determine whether accommodative amplitude differs between these two refractive error groups. To compare amplitudes measured in response to lens blur versus proximal blur, we performed a Pearson correlation coefficient analysis and an analysis of the difference versus the mean.[17]

Data from this study reflect a large age range of individuals from young to middle age. A primary goal of this study was to define the objectively measured accommodative amplitude function by age from a relatively young age. To determine whether the findings are in agreement with those of previous objective studies of amplitude in middle-aged individuals, data were pooled with data from four previously published studies in which accommodation was measured objectively in response to minus lens blur.[8–11] Data from the two most recent studies were obtained directly from one of the study authors, whereas the data from the older studies were extracted from scanned images of the published figures from the studies by using image analysis to determine the coordinates of each point from the plots. In addition to comparing the measurements of amplitude for the middle-aged subjects tested in the present study, pooling the data from the five studies provided a more complete description of the function of objectively measured accommodative amplitude by age for ages 3 to 70 years. Data were analyzed with commercial software (SAS ver. 9.1 Proc NLIN; SAS Institute, Cary, NC). A sigmoidal curve was fit to the pooled data.

RESULTS

Autorefractor measurements while viewing the distance target averaged 0.08 ± 0.41 D (mean ± SD) for all subjects. Linear regression analysis revealed no significant relationship between distance autorefractor measurements (distance corrected refraction) and age ($P > 0.08$). A *t*-test analysis indicated a significant difference ($P < 0.01$) in distance autorefractor measurements for corrected myopic (−0.06 D) and emmetropic (0.19 D) subjects. Measurements for other refractive groups were not compared, given the small number of hyperopic and astigmatic subjects in the study population. The results of this analysis indicate that subjects did not have large uncorrected refractive errors.

Maximum accommodative amplitudes are shown as a function of age for all subjects in Figure 2. Studentized residuals were calculated for each subject, to identify any subjects whose accommodative amplitudes fell significantly outside of the range of the group data. The studentized residual is defined as the residual of a data point from the fitted curve divided by the estimate of its standard deviation. It is expressed as a *z*-score which indicates the number of standard deviations that the point is away from the overall fit. A *z*-score lower than −2.00 was used as a cutoff criterion, and it identified six young subjects as outliers from the overall data set. The data from those subjects are circled in Figure 2. Aside from having a large difference from the mean, these subjects were also quite young. For the purposes of the analysis, these subjects were identified as outliers and omitted. Possible explanations for the poor performance of these subjects are given in the Discussion section.

The data from the remaining 134 subjects were fit with a curvilinear regression described by the equation: predicted amplitude (D) = 7.33 D − 0.0035(Age − 3)^2; $R^2 = 0.59$ ($P < 0.001$). The function fit to the data was centered at age 3, because this was the age of the youngest subjects tested. The statistical term centering refers to redefining the coordinates so that the 0 value of the predicting variable is meaningful and of interest regarding the data set. When centering a function at age 3, the intercept represents the amplitude of accommodation for a 3-year-old individual and subsequent calculations of amplitude must therefore be made by subtracting 3 from the age of the individual for whom amplitude is being predicted, as is shown in the equation. Tangent fit analysis to the curvilinear function indicates that accommodative amplitude decreases

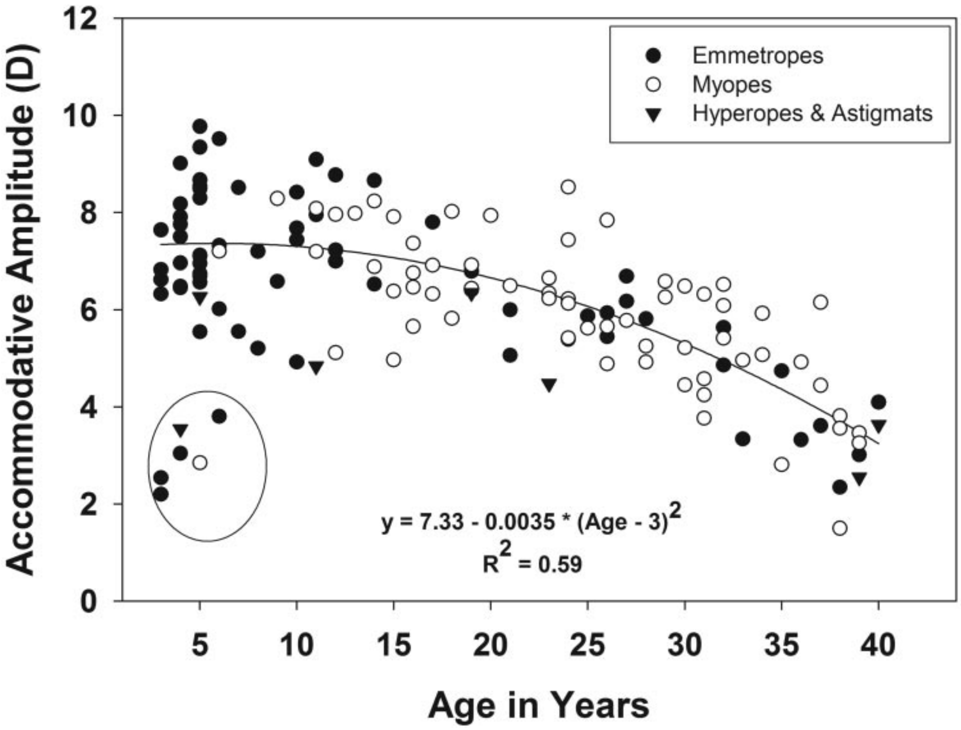

FIGURE 2. Maximum accommodative amplitudes for subjects aged 3 to 40 years. The six *circled* data points represent potential outliers, all of whom had studentized residuals with a *z*-score of less than −2.00.

minimally throughout childhood and begins to decrease more rapidly around the age of 20.

To look for effects of refractive error on accommodative amplitude, it is important to control for age effects because refractive error, especially myopic refractive error, is often related to age.[18] After statistical correction for age effects, no significant relationship between accommodative amplitude and refractive error was found, indicating an equal distribution of accommodative amplitudes between myopic and emmetropic subjects and similar curvilinear fits to the data from each group as a function of age ($P > 0.5$).

The accommodative amplitudes measured on the subset of 22 adults using trial lens blur in comparison to proximal targets to stimulate accommodation are shown in Figure 3. It can be seen in Figure 3A that the data are highly correlated between the two objective techniques (Pearson correlation coefficient = 0.987; $P < 0.01$). However, the data fall above the 1:1 line, indicating a systematically greater response with the technique using proximal blur as a stimulus for accommodation. The difference between these two techniques is illustrated in the Bland-Altman plot in Figure 3B in which the solid line indicates the signed averaged difference (0.35 D), and the dashed lines show ±2 SD, or the 95% limits of agreement (−0.08–0.77 D).

Figure 4 shows the distribution of objectively measured accommodative amplitudes pooled from this study and four previously published studies ($n = 376$). Using a criterion of absolute studentized residuals greater than 2.00 identified 27 potential outliers; however, explanations for the potential differences in the performance of these subjects were not available because they came from previously published studies. Data analysis was performed both with and without the potential outliers and resulted in the same curve fit to the data; thus, none of the potential outliers was omitted from the analysis. A LOESS smoothing function (locally weighted polynomial) was fit to the data to provide a description of the data without making any prior assumptions about the shape of the data. Although the LOESS function accounted for a high proportion of the variance (0.90), this function does not provide an equation from which to derive predicted values and is nonmonotonic because of noise from sampling variability. For this reason, a sigmoidal function was fit to the data that is monotonic and provides an equation that can be used to predict accommodative amplitudes by age. As is seen in Figure 4, the sigmoidal function is highly descriptive of the data and is overlapped by the LOESS function at all ages. The sigmoidal function fit to all 376 subjects' data was significant ($F_{(3,372)} = 886.29$, $P < 0.001$). The proportion of variance explained by the sigmoidal model is similar to that of the LOESS (0.88) and the equation that describes the curve is: predicted amplitude = $7.083/(1+e^{[0.2031(\text{age} - 36.2) - 0.6109]})$. To predict amplitudes by using this equation, the entered age must be adjusted by subtracting 36.2. The purpose of this adjustment is that 36.2 was the mean age of the distribution of the data and the value on which the sigmoidal fit was centered. A quick reference of predicted amplitudes for each 5-year interval calculated from this formula is shown in Table 1. This model of the data indicates a minimal decline in accommodative amplitude for individuals throughout childhood with a rapid decline in amplitude from age 20 into the 50s, when amplitude reaches a level of 0.5 D and continues to decline slowly toward 0.

DISCUSSION

The data from this study provide information about the change in amplitude of accommodation as a function of age measured objectively in a large age range of individuals. Unique to this study is a description of the accommodative function by age for individuals as young as 3 years. Contrary to the large amplitudes reported with the subjective push-up technique, this study found predicted average amplitudes only slightly greater than 7 D in children from the age of 3 into the teenage years. This relatively stable amplitude does not begin to decline rapidly until the third decade of life.

Previous studies of accommodative amplitude in young children using the subjective push-up technique vary in their descriptions of amplitude as a function of age,[6,7,19,20] presum-

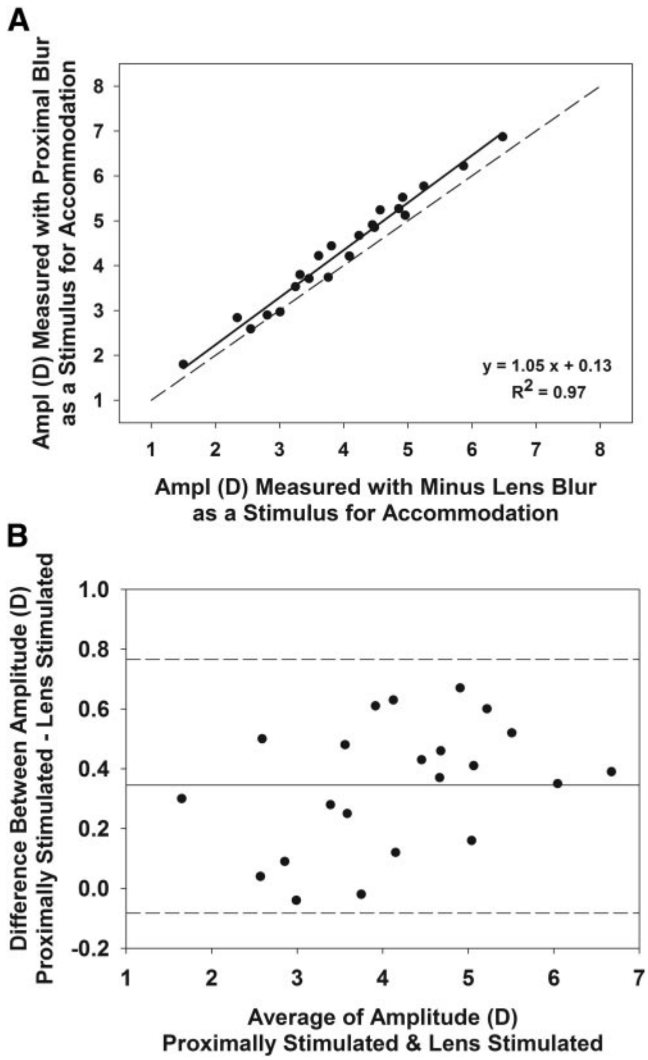

FIGURE 3. Comparison of maximum accommodative amplitudes measured using minus lens blur as a stimulus for accommodation versus proximal blur as a stimulus for accommodation in 22 adult subjects. (**A**) Linear regression analysis. (**B**) Difference-versus-mean plot. *Solid line*: mean difference between methods; *dashed lines*: 95% limits of agreement (±1.96 SD).

ably due to the difficulty in performing or interpreting the push-up test accurately in young children who do not comprehend the endpoint (first blur) of the task. In 1966, Wold[7] performed subjective amplitude tests on 125 children between the ages of 5 and 8 years and suggested that amplitude remains stable over that age range. The data from this study support Wold's findings, although, as expected, the amplitudes measured objectively in the present study are much lower than those that he reported after using the subjective technique. Figure 5 shows a comparison from several additional studies that used subjective measurements to the objective data reported in this article. The studies shown in Figure 5 include the predicted line of Hofstetter,[5] monocular subjective push-up test amplitudes measured by Wold[7] in 125 children aged 5 to 8 years, binocular subjective push-up test amplitudes measured by Eames[6] in 899 children aged 5 to 8 years, monocular subjective push-up test amplitudes measured by Sterner et al.[19] in 72 children aged 6 to 10 years, and subjective monocular amplitudes measured by Woodruff et al.[20] in 286 children aged 3 to 11 years using increasing minus lenses until blur was reported.

Although the objective technique used in this study may be a more appropriate task for young patients than the subjective push-up test because no subjective feedback or understanding of first blur is required, six of the young subjects shown in Figure 2 performed significantly worse than their peers. There are several possible explanations for the poor performance of the six young outliers. The simplest is that perhaps these subjects have an accommodative dysfunction and truly do have accommodative amplitudes below the mean. A second explanation is that although the measurements were objective, there is a voluntary component to accommodation that requires the subject to elicit an accommodative response to clear the target. It is possible that these six young subjects were not interested in the task and did not exert the effort to produce maximum accommodation. However, all participants in the study were willing and cooperative, including these six. Perhaps then it was not a voluntary inability to complete the task, but rather an involuntary one. All six of the outliers had measured amplitudes of accommodation of approximately 3.00 D, which is the accommodative demand to the physical target positioned at 33.33 cm as viewed without lenses. When presented with the 3-D stimulus, only one of the six subjects had a low response outside the range of the entire group of subjects aged 3 to 5 years. Perhaps then, the outlying subjects failed to demonstrate larger amplitudes of accommodation because they were unable to interpret and respond to the minus lens blur as a stimulus for accommodation, which was used to create demands greater than 3 D. To test this theory for these subjects, additional measurements were made by moving the target progressively closer from the 33.33-cm starting point without additional minus lenses. Four of the six subjects showed an increase in accommodative response to proximal blur. Three of them achieved accommodative amplitudes within the range of minus-lens–induced blur amplitudes of their peers.

Unfortunately, because of the physical dimensions of the Grand Seiko autorefractometer, we could not moved the target close enough to measure maximum amplitudes of accommodation in this way.

The improvement in accommodative amplitude demonstrated for some of these young children when tested with proximal blur suggests that maturation of the accommodative response to different cues for accommodation warrants future study in young children. In this study, we investigated the effects of proximal cues on amplitude in a subset of adults and found that the mean amplitude increased by only 0.35 D with proximal cues. It remains unknown whether the outcome measures of this study would have differed if objective amplitudes in response to proximal stimuli could have been obtained for all subjects; however, given that most of the young children responded well to the minus blur stimulus, it is expected that their responses to proximal blur would show an increase on the same order of magnitude reported for adults. The prediction would then be that a proximal stimulus would not change the shape of the function, but rather would shift it upward uniformly by a small amount for the nonpresbyopic ages.

The target used in this study contained a range of print sizes and picture detail sizes in an attempt to maintain the attention and cooperation of the youngest subjects. It is possible that accommodative responses differed depending on which print size the subject fixated. To explore this potential variable, a comparison of accommodative responses to the various print sizes was made for 11 subjects who were instructed precisely what part of the target to fixate for each of three measurements (smallest print, largest print, and picture target). The greatest difference in accommodative response was found between the largest and smallest print sizes and had a mean difference of 0.15 ± 0.25 D. This difference could impact the response at

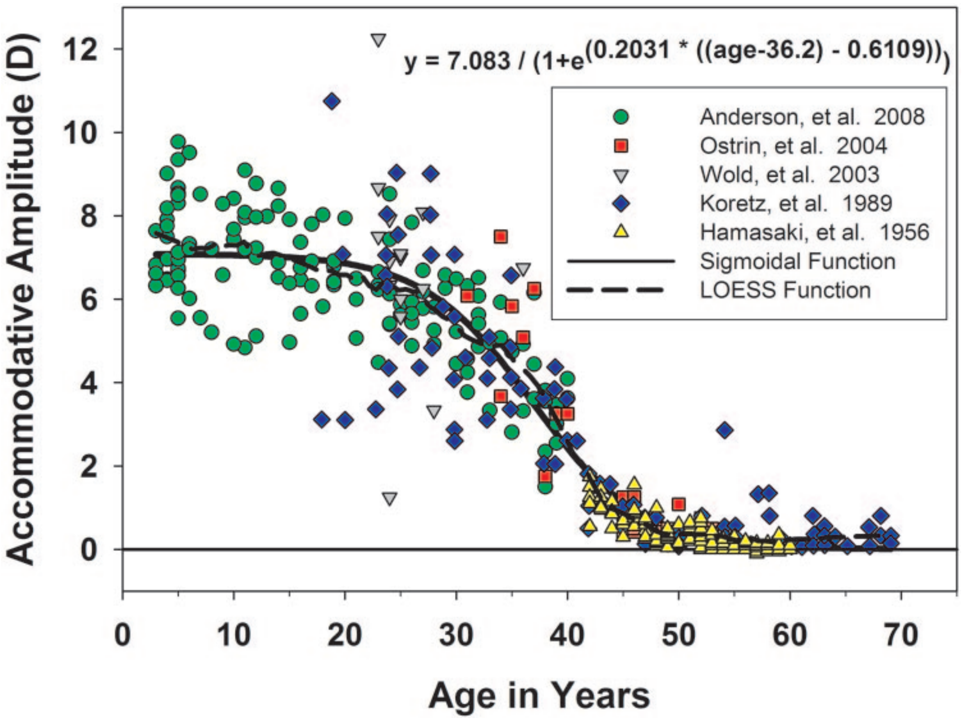

FIGURE 4. Maximum accommodative amplitudes for subjects pooled from the present study and four previous published studies: Ostrin and Glasser,[11] Wold et al.,[10] Koretz et al.,[8] and Hamasaki et al.[9]

each given demand presented, although not systematically; however, it should not impact the overall maximum amplitude measured other than potentially requiring a greater demand to be presented to elicit the maximum response of those subjects viewing the larger print sizes.

Concerning the topic of accommodative amplitude and its relation to refractive error, this study did not find any significant differences in maximum amplitude between myopic and emmetropic subjects. Investigators who have measured accommodative amplitude with the subjective push-up test have reported varied associations with refractive error. McBrien and Millodot[21] reported greater amplitudes of accommodation in myopic subjects aged 18 to 22 years than in emmetropic and hyperopic subjects of the same age, whereas Fisher et al.[22] found no significant differences in push-up amplitudes between myopic, emmetropic, and hyperopic subjects aged 21 to 35 years. More recently, Fong[23] and Allen and O'Leary[24] independently reported lower amplitudes of accommodation in their young adult myopic subjects when compared with emmetropic subjects of similar ages. All of these studies used the subjective push-up test to measure accommodative amplitudes. As mentioned previously, the push-up test includes the depth of field and is not a true measure of accommodative response. Subjects with less sensitivity to blur may yield a greater outcome measure with the push-up test producing an overestimation of their true amplitude of accommodation. Previous literature has suggested that there may be an association between blur sensitivity and refractive error, with myopic subjects showing less sensitivity to blur.[25] Such an association could account for some of the differences in amplitude observed between refractive groups in previous studies, especially in the cases of myopic subjects showing greater accommodative amplitudes. Unlike the subjective push-up test, the objective measurements from this study should not be affected by differences in blur sensitivity among subjects. Although a decreased sensitivity to blur could impact the stimulus response function of objectively measured accommodative responses, the measurement of maximum amplitude should remain unaffected by differences in blur sensitivity other than the potential need for presenting a greater stimulus demand to elicit the maximum amplitude in those subjects with decreased sensitivity.

Comparing data from previous studies with the data from this study demonstrates good agreement across studies in objective findings for similar ages tested (20–40 years in the present study). Data pooling with the findings from this study allows a complete picture of the function of accommodative amplitude to lens-induced blur with age to be described from the very young to the age at which little to no amplitude remains. However, there are limitations in making direct comparisons when pooling data from multiple studies in which recruitment criteria and methodologic techniques differ. For example, age and refractive error inclusion criteria varied between each study. Ostrin et al.[11] reported 31 subjects ranging from 31 to 53 years of age with refractive errors no greater than 2.50 D, whereas Wold et al.[10] included 15 subjects between ages 23 and 36 years with no greater than a 2.00-D refractive

TABLE 1. Predicted Monocular Accommodative Amplitude as Measured Objectively with the Grand Seiko Autorefractor

Age	Predicted Amplitude of Accommodation (D)
3	7.08
5	7.07
10	7.05
15	7.00
20	6.86
25	6.49
30	5.66
35	4.19
40	2.43
45	1.13
50	0.46
55	0.17
60	0.06
65	0.02
69	0.01

Values are based on the sigmoidal function fit to the data in Figure 4.

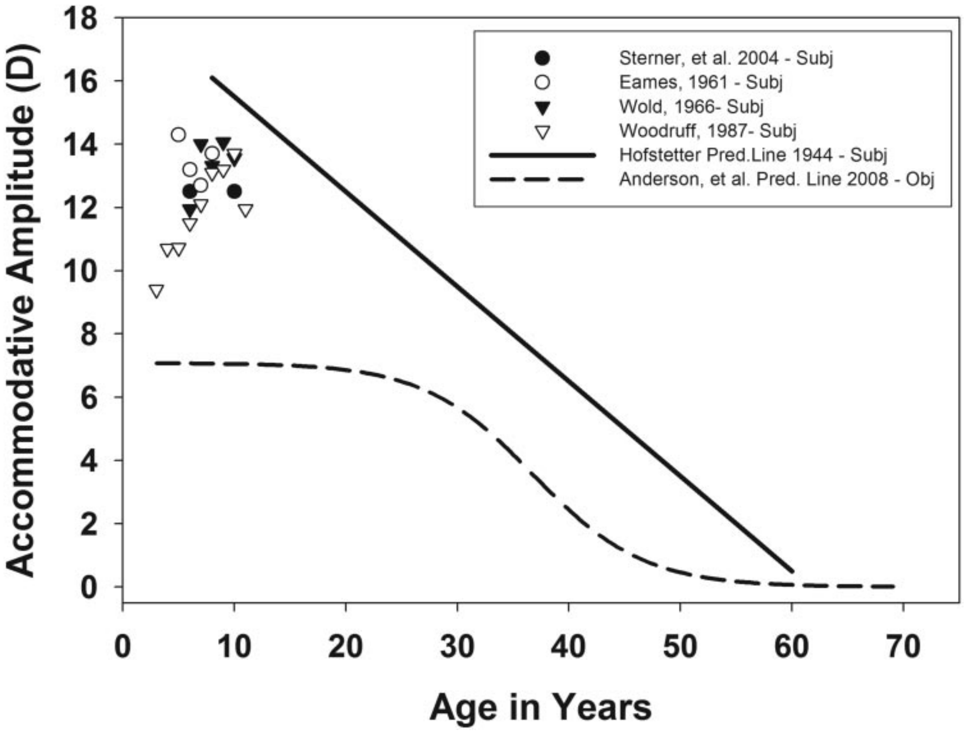

FIGURE 5. Maximum accommodative amplitudes from previous studies using the subjective push-up test are shown in comparison to the sigmoidal function of objective accommodative amplitudes presented in the present study: Sterner et al.,[19] Eames,[6] Wold,[7] and Woodruff.[20] *Solid line*: the predicted line of Hofstetter[5] for mean accommodative amplitude; *dashed line*: predicted function presented in this study for objective accommodative amplitudes.

error. Hamasaki et al.[9] included 106 subjects between ages 42 and 60 years and did not specify refractive error requirements, whereas Koretz et al.[8] included 100 subjects aged 18 to 70 years with refractive errors less than 2.00 D. In addition, the methods used in each study varied; however, they were similar, in that all reported monocular objectively measured amplitudes of accommodation stimulated with increasing lenses of more minus power. Hamasaki et al.[9] used the objective technique of stigmatoscopy, whereas investigators in the other three studies used the Hartinger Coincidence Refractometer to measure accommodation objectively.[8,10,11] In the present study, the Grand Seiko autorefractor was used, as it is easy to use in individuals of all ages, especially young children. A recent study has compared the Hartinger and the Grand Seiko and found them to provide comparable results.[26] Despite the differences in measurement apparatuses and recruitment criteria, the findings from all studies are in good agreement over the similar ages tested.

CONCLUSIONS

The findings of this study suggest that minus-lens–induced accommodative amplitude is relatively stable throughout childhood at a mean magnitude of approximately 7 D and does not begin a rapid decline until the third decade of life. As reported in previous studies, this work supports the finding that objective measurements of accommodation are much lower than those obtained by subjective methods. No differences were found in accommodative amplitude between myopic and emmetropic individuals. When the data from this study are pooled with data from previous studies, a picture of accommodative amplitude as a function of age can be derived as a sigmoidal function, with the most rapid decreases in accommodation occurring between the ages of 20 and 50 years. These findings could have clinical implications for determining how much uncorrected hyperopic refractive error can be tolerated in young patients. Also, given that this study found similar amplitudes of accommodation up to about age 20, the results could have implications for pharmacologically controlling accommodation when assessing refractive error beyond the preschool years.

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