Article ▸ Lag of Accommodation Between 5 and 60 Years of Age

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ABSTRACT

Purpose: Assessment of the accommodative response is an essential part of the optometric examination. In the clinic, the practitioner needs to determine the response to a given stimulus, typically positioned at the habitual working distance. This study used dynamic retinoscopy to examine the effect of age on both the mean and normal range of accommodative lag to a 2.50D accommodative stimulus.

Method: The lag of accommodation was assessed in 1296 subjects between 5 and 60 years of age using either the Nott technique (for subjects under 40 years of age) or monocular estimate method (MEM) retinoscopy (for subjects over 40 years of age).

Results: No significant change in lag of accommodation as a function of age was observed for subjects under 40 years of age. The mean lag in this age group was 0.54D, with almost all subjects having lags between 0 and 1.00D. A marked increase in accommodative lag occurred after 40 years of age, with the accommodative response reaching zero by 54 years of age. The effect of age was best described by an exponential function having the equation: lag = 0.945 - (0.057*age) + (0.0016*age^2). Accommodative lag did not vary significantly with the type of underlying refractive error.

Conclusions: The accommodative response to a 2.50D stimulus remained constant until 40 years of age, with a mean value of approximately 0.50D. Subsequently, a marked increase in accommodative error was observed, concurrent with the onset of clinical presbyopia. Dynamic retinoscopy provides a simple technique for quantifying accommodation in the clinical setting.

Keywords: Accommodation, age, dynamic retinoscopy, lag of accommodation, presbyopia

Introduction

Assessment of the accommodative response to a near stimulus is an important part of the clinical optometric examination.[1] Many patients report symptoms during nearwork, and these may be related to inappropriate levels of accommodation. It is well established that the accommodative response is generally less than the accommodative stimulus (the so-called lag of accommodation) when viewing most near targets (i.e., for stimulus levels greater than approximately 1D). A lag of accommodation (defined as the accommodative stimulus minus the accommodative response, with both parameters being measured in diopters) that exceeds the depth-of-focus of the eye will result in blurred vision. However, the majority of patients will be able to function comfortably with clear near vision provided the lag is less than the depth-of-focus of the eye.

It is also well established that the maximum accommodation (i.e., amplitude of accommodation) declines with age. Two recent studies[2,3] have demonstrated that the magnitude of this maximum response is significantly lower than was reported previously in the classic studies of Donders[4] and Duane.[5] Indeed, in both recent investigations, the maximum accommodative response for the youngest subjects evaluated (3-5 years of age) was less than 10D.[2,3]

In considering the effect of age on the lag of accommodation to targets at a more habitual working distance, Anderson et al.[6] reported that for subjects between 3 and 20 years of age, the lag to a 3D stimulus decreased at a rate of -0.034D per year. Further, their results showed minimal change in the mean lag for this stimulus level in subjects up to 40 years of age. The accommodative response was measured using an objective, open-field, infra-red optometer (Grand Seiko WR-5100K). When considering the effect of age on the accommodative response in both pre-presbyopic and presbyopic individuals, a number of studies have examined changes in the slope of the accommodative stimulus-response function with age. For example, both Mordi and Ciuffreda[7] and Roberts et al.[8] reported minimal change in the gradient of the linear region of the stimulus-response function from 20 to 45 years of age and from 5 to 35 years of age, respectively. What remains unclear is precisely when the within-task accommodative response does start to decline, concurrent with the onset of clinical presbyopia.

In the clinical setting, the practitioner is frequently more interested in the response to a single stimulus (typically the habitual working distance) rather than a wide range of demands. As noted above, it is not well documented as to when the lag of accommodation starts to increase with age. Indeed, the expected range of values in a normal population for this parameter across a wide range of ages (both pre-presbyopic and presbyopic) has not been quantified. This is critical for a clinician, who needs to be able to state whether the patient's response falls into the normal category. Roberts et al.[8] speculated that an accommodative gain value of 0.70 might be a useful measure; i.e., if the response was 70% of the stimulus, then the target would be seen clearly. This is equivalent to a 1.75D response for a 2.50D stimulus, or a 0.75D lag of accommodation. These authors did point out that further work was required before this metric could be recommended clinically.

One study that did examine the lag of accommodation across a wide age range was that of Whitefoot and Charman.[9] These authors used Sheard's dynamic retinoscopy technique[10] to assess the lag of accommodation to a 3D stimulus in 221 "clinically normal" subjects between 10 and 80 years of age. With this technique, a target is attached to the retinoscope at the patient's usual reading distance. Retinoscopy is performed through the distance refractive correction, and spherical lenses are added until a neutral reflex is observed. The lag of accommodation was originally defined by Sheard as the lens power which provides 'the first indications of a neutral shadow'.[11] Whitefoot and Charman observed a significant positive linear correlation between lag and age, with the lag increasing at a rate of 0.034D/year across the total age range.[9] Based on the linear regression function provided, the authors predicted a lag of accommodation of 0.95 and 1.63D for subjects of 20 and 40 years of age, respectively. The authors also noted the wide scatter of findings, with lags for subjects under 20 years of age exceeding 2D on occasions. However, the addition of plus lenses in young subjects has been shown to produce a reduction in the accommodative response, thereby increasing the observed lag.[12-14] Indeed, when the lag was measured in the same subjects using a laser optometer,[15] the mean lag for subjects between 13 and 37 years of age was around 0.50D. However, even with this optometer, lags greater than 1.5D were also observed (to the 3D stimulus) in this age group.

Indeed, examination of previous investigations shows a surprisingly wide range of lags of accommodation in reportedly normal subjects. For example, while several studies have reported mean values between 0.25 and 0.35D for stimuli between 1 and 4D,[16-18] Gwiazda et al.[19] noted a mean lag of accommodation (when accommodation was stimulated by physically displacing the target rather than using supplementary lenses) to a 3.0D stimulus of approximately 0.75 and 1.00D in emmetropic and myopic children between 5 and 17 years of age. In addition, the Correction of Myopia Evaluation Trial 2 Study Group measured the lag of accommodation to a 3D accommodative stimulus in 168 children between 8 and 12 years of age. When quantified using either an infra-red open-field autorefractor, MEM, or Nott retinoscopy, they reported that 69%, 51%, and 27% of the population (N=168) exhibited a lag of accommodation exceeding 1.00D, respectively.[20] The aim of the present investigation was to examine the effect of age on both the mean and normal range of lag of accommodation to a 2.50D stimulus in subjects between 5 and 60 years of age.

Method

The subject population examined here was part of a larger investigation of accommodation and age, and their characteristics have been described previously.[3] Briefly, 1296 subjects were included, all of whom were in good physical health. One hundred fourteen subjects were excluded, either because they had amblyopia, strabismus, anterior and/or posterior eye disease, or they did not complete all testing. Our prior publication noted that the mean objectively measured amplitude of accommodation as a function of age for this population was very similar to that reported by Anderson and Steubing[2] for a subject group based in the United States. The study followed the tenets of the Declaration of Helsinki and was approved by the Bioethics Committee at the Fundación Universitaria del Área Andina.

Subjects between 5 and 19 years of age were recruited from the public schools in the city of Pereira, Colombia. Subjects between 20 and 60 years of age were drawn from the students, faculty, and staff at the Fundación Universitaria del Área Andina, as well as from their relatives and friends. Informed consent was obtained from all adult participants after a full explanation of the experimental procedures, while both parental consent and child assent were obtained from all participants younger than 18 years of age. Exclusion criteria included: best-corrected logMAR VA greater than 0.1 (at distance or near), refractive error outside the range of ±6.00D (sphere) or 3.00D (cylinder), strabismus, amblyopia, monocular accommodative facility less than 8 cycles/min (since this would indicate difficulty varying blur-driven accommodation, which would be predicted to alter the lag of accommodation[10]), and aphakia. In addition, any subject reporting a history of significant eye or head injury, ocular surgery, or who was taking any medication that could affect accommodation was also excluded.

All subjects were examined in the optometry clinic at the university. This evaluation included logMAR visual acuity at distance and near, static (non-cycloplegic) retinoscopy and subjective refraction, prism-neutralized cover test, near point of convergence (NPC), stereopsis, and assessment of the anterior and posterior segment of the eye using a slit lamp and direct ophthalmoscopy through an undilated pupil.

Data were collected by 10 optometrists, all of whom were faculty members at the University with at least 5 years of post-graduate experience. All of the practitioners followed the standard protocol as described below for obtaining measurements. For subjects under 40 years of age, the accommodative response was quantified using Nott retinoscopy[10] for an accommodative stimulus of 2.50D. The target comprised an 8 x 6 array of letters or pictures, each of which was 1.2 mm high (corresponding to 0.31 logMAR), which was observed binocularly. The subject viewed the target (under binocular viewing conditions) through their distance refractive correction, and the experimenter adjusted the retinoscopy working distance until a neutral reflex was seen. The accommodative response was quantified as the reciprocal of the distance (in meters) at which the neutral reflex was observed. However, this technique was not practical for subjects over 40 years of age, because of the reduced accommodative response that produces a neutral point further away from the subject. Accordingly, the Monocular Estimate Method (MEM)[10,21] was used for these older participants. The target described above was attached to the retinoscope at a distance of 0.4m. Rather than changing the observer's working distance, plus trial lenses were added over the distance refractive correction in front of the eye being tested until a neutral reflex was observed. The lag of accommodation (i.e., accommodative stimulus – accommodative response) was quantified as the lowest additional plus lens that produced a neutral reflex. In order to minimize the relaxation of accommodation typically produced by the addition of plus lenses,[12-14] the evaluator did not keep the supplementary plus lens in place for more than one second.

Data Analysis

A descriptive univariate analysis of the data was performed, and the mean and standard deviations were calculated. Differences in the lag of accommodation with age and refractive groups were evaluated using analysis of variance. The relationship between accommodative lag and age was assessed using a two-phase regression analysis (i.e., between 5 and 39 years of age and between 40 and 60 years of age). The normal range of accommodative lag was defined by the 3rd and 97th percentiles. All calculations were performed using the statistical software STATA 10.0 (http://www.stata.com).

Results

Findings from 1269 subjects were included in this study. Only data from the right eye is presented. The mean visual acuity for subjects between 5 and 60 years of age was -0.06 logMAR (SD = 0.09). Based on non-cycloplegic static retinoscopy, 738 subjects were classified as emmetropic (i.e., spherical equivalent between -0.25 and +0.50), 313 as hyperopic (≥ +0.75), and 218 as myopic (≤ -0.50D).

Mean values of accommodative lag as a function of age are shown in Figure 1 and Table 1. One-way analysis of variance showed significant changes in lag with age ($F_{10,1268}$ = 623.17, $p<0.001$). However, post-hoc Bonferroni analysis indicated no significant change below 40 years of age (see Table 2). Linear regression also confirmed the finding of no significant change with age below 40 years of age (r^2 = 0.001; y = 0.512 + 0.0013*age; p = 0.144) but a significant increase in lag of 0.08D per year between 40 and 60 years of age (r^2 = 0.495; $p<0.001$; y = -1.58 + 0.08*age). The complete data set is best described by an exponential function having the equation: lag = 0.945 - (0.057*age) + (0.0016*age^2); [r^2: 0.775, $p<0.001$].

Mean values of accommodative lag as a function of the underlying refractive group are shown in Table 3. Two-factor (age, refractive group) analysis of variance showed that age was significant ($F_{10,1268}$ = 417.40; $p<0.001$), but the differences with refractive error were not significant ($F_{2,1268}$ = 0.24; p = 0.79). To estimate the expected range of accommodative lag as a function of age, the 3rd, 50th, and 97th percentiles were calculated. These values are provided in Table 4.

Discussion

The results illustrated in Figure 1 show no significant change in the lag of accommodation to a 2.50D stimulus for subjects between 5 and 40 years of age. This is consistent with the earlier reports of both Mordi and Ciuffreda[7] and Roberts et al.[8] In addition, examination of Table 4 indicates that the mean lag is very close to 0.50D across this age range, with almost all subjects having lags between zero and 1.00D. However, above 40 years of age, a dramatic increase in lag occurs. Indeed, the mean accommodative lag becomes equal to the accommodative stimulus (reflecting an accommodative response of zero) at 54 years of age. This is in agreement with the findings of Hamasaki et al.,[22] who stated that after 54 years of age, the amplitude of accommodation "is insignificant and can be considered to be zero." Accordingly, it is reasonable to conclude that for this population, clinically significant presbyopia becomes manifest after 40 years of age and is completed (i.e., no further accommodative loss is apparent) by 54 years of age. It should also be noted that age-related loss of accommodative ability varies with ethnicity and geographic location,[23] and so these specific age ranges may not apply to populations from other parts of the world.

A significant limitation of this study is that pupil diameter was not controlled. Age-related pupillary miosis will increase the depth-of-focus of the eye, thereby reducing the stimulus to accommodation.[24,25] However, Winn et al. observed a linear decrease in pupil size with age in subjects between 17 and 83 years of age,[25] which would not account for the dramatic increase in accommodative lag observed here after 40 years of age (see Figure 1). Further, the lack of a significant change in lag between 20 and 40 years of age, when a concurrent reduction in pupil size would be anticipated, suggests that the increase in depth-of-focus of the eye in this age range is small. Indeed, Atchison et al.[26] reported that as long as the pupil diameter exceeded 3mm, then the effect of varying pupil size on noticeable blur would be minimal. The mean finding of an accommodative lag around 0.50D is in line with previous measurements of the depth-of-focus of the eye, which have generally ranged between 0.2 and 0.5D depending on factors

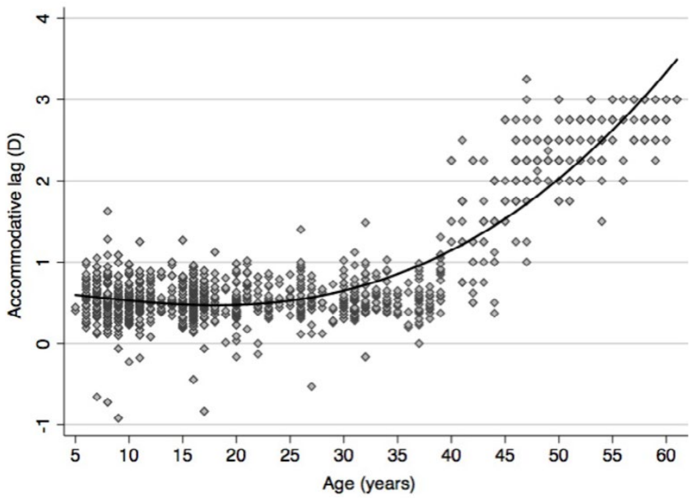

Figure 1. *Lag of accommodation to a 2.50D stimulus as function of age (N=1269). The data is described by an exponential function having the equation: Lag = 0.945 - (0.057*age) + (0.0016*age²).*

Table 1. Mean and Standard Deviations of the Accommodative Lag to a 2.50D Stimulus. Subjects were between 5 and 60 years old and were grouped in five-year bins.

Age group (years)	N	MEAN (D)	SD
5 to 9	223	0.51	0.32
10 to 14	250	0.55	0.23
15 to 19	193	0.53	0.28
20 to 24	122	0.53	0.21
25 to 29	63	0.52	0.27
30 to 34	125	0.55	0.22
35 to 39	64	0.58	0.25
40 to 44	54	1.43	0.54
45 to 49	72	2.16	0.42
50 to 54	56	2.37	0.37
55 to 60	47	2.74	0.24
All subjects	1269	0.83	0.72

Table 3. Mean Values and Standard Deviation (SD) of Spherical Equivalent Refractive Error and Accommodative Lag in Diopters (D), as a Function of Underlying Refractive Group

	N	Mean refractive error (D)	Refractive error SD (D)	Mean lag of accommodation (D)	Lag of accommodation SD (D)
Emmetropic	738	+0.15	0.23	0.75	0.63
Hyperopic	313	+1.15	0.61	1.00	0.90
Myopic	218	-1.03	0.88	0.75	0.64
Total	1269	0.20	0.86	0.83	0.72

Table 4. 3rd (P3), 50th (P50), and 97th (P97) Percentiles of Values of Accommodative Lag (D) to a 2.50D Stimulus Measured Using either Nott Retinoscopy or MEM Retinoscopy techniques. Nott retinoscopy was used for subjects between 5 and 39 years of age, and MEM retinoscopy was used for subjects between 40 and 60 years of age.

Age group (years)	P3	P50	P97
5 to 9	-0.07	0.51	1.06
10 to 14	0.17	0.52	0.99
15 to 19	-0.07	0.54	0.94
20 to 24	0.02	0.52	0.97
25 to 29	0.06	0.50	1.03
30 to 34	0.30	0.50	1.02
35 to 39	0.19	0.55	1.01
40 to 44	0.45	1.50	2.34
45 to 49	1.25	2.25	3.20
50 to 54	1.68	2.38	3.00
55 to 60	2.11	2.75	3.00

Table 2. Mean Differences (MD) of Accommodative Lag by Age Group in Years

Age Group		5 to 9	10 to 14	15 to 19	20 to 24	25 to 29	30 to34	35 to 39	40 to 44	45 to 49	50 to 54
10 to 14	**MD**	0.03									
	p -value	>0.99									
15 to 19	**MD**	0.015	-0.02								
	p -value	>0.99	>0.99								
20 to 24	**MD**	0.01	-0.02	-0.01							
	p -value	>0.99	>0.99	>0.99							
25 to 29	**MD**	0.01	-0.02	-0.01	-0.01						
	p -value	>0.99	>0.99	>0.99	>0.99						
30 to 34	**MD**	0.03	0.01	0.02	0.02	0.02					
	p -value	>0.99	>0.99	>0.99	>0.99	>0.99					
35 to 39	**MD**	0.07	0.04	0.05	0.06	0.06	0.04				
	p -value	>0.99	>0.99	>0.99	>0.99	>0.99	>0.99				
40 to 44	**MD**	0.92	0.89	0.9	0.91	0.91	0.89	0.85			
	p -value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			
45 to 49	**MD**	1.65	1.62	1.63	1.64	1.64	1.62	1.58	0.73		
	p -value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		
50 to 54	**MD**	1.85	1.82	1.84	1.84	1.84	1.82	1.78	0.93	0.2	
	p -value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.006	
55 to 60	**MD**	2.22	2.2	2.21	2.21	2.22	2.19	2.16	1.31	0.58	0.37
	p -value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

such as pupil diameter, target luminance, contrast, color, and the experience of the subject.[27-31] Nevertheless, some of the decrease in accommodative responsivity, especially in the older subjects, could have resulted from an increase in the depth-of-focus of the eye.

In examining the distribution of the findings, which can be considered as the difference between the 3rd and 97th percentiles (see Table 4 and Figure 1), it is apparent that between 5 and 40 years of age, there is minimal change in the variance. The vast majority of subjects exhibit a lag of accommodation between 0 and 1.00D. This is in contrast to the results of the Correction of Myopia Evaluation Trial 2 Study Group, who reported that 51% and 27% of the 168 subjects between 8 and 12 years of age had a lag of accommodation exceeding 1.00D when measured using MEM and Nott retinoscopy, respectively.[20] In examining the 306 subjects from the present study within this age range (8-12 years of age), only 8 individuals (2.6%) had a lag of accommodation greater than 1.00D. Further, the mean lag measured here for this age range was 0.51D (SD = 0.29D; range -0.92 to 1.63D).

The lower number of large lags of accommodation (>1.00D) observed in the present investigation may be related to the size of the target used. For example, Gwiazda et al.[19] used an array of 20/100 letters, which could still be resolved with a smaller accommodative response. The Correction of Myopia Evaluation Trial 2 study did not specify the letter size.[20] Further, the use of supplementary minus lenses by Gwiazda et al., especially in pediatric patients, may be less effective in stimulating accommodation. Indeed, Chen and O'Leary[18] compared accommodative accuracy when accommodation was stimulated either in free space (directly viewing a near target at a distance of 1m) or by viewing a far target through a -1.00D lens in 59 emmetropic children between 2 and 5 years of age. The mean lag of accommodation for the free-space and minus-lens conditions was 0.24D (SEM = ±0.03D) and 0.69D (SEM = ±0.08D), respectively ($p<0.01$). These findings indicate that pre-school children may respond poorly to accommodative stimuli created by the introduction of minus lenses. Similarly, Abbott et al.[32] reported accommodation stimulus-response gradients of 0.95, 0.85, and 0.79D/D, respectively, when accommodation was stimulated by viewing a target at 25cm through supplementary plus lenses, physically displacing the target, or viewing a target at 4m through supplementary minus lenses. Therefore, especially in children, it is better to increase the accommodative demand by moving the target closer to the observer, rather than by introducing additional minus lenses.

Another significant issue with the present investigation was the change in measurement technique for subjects below and above 40 years of age. This was required because the older subjects were unable to resolve the target clearly at 40cm without supplementary plus lenses. Previous investigations have demonstrated that introduction of such lenses will cause a reduction in the accommodative response.[14] Indeed, Cacho et al. recorded a significantly higher mean lag of accommodation using MEM retinoscopy (mean = 0.74D when recorded through the subjective refraction), when compared with Nott retinoscopy (mean = 0.42D), in subjects between 15 and 35 years of age.[33] However, other investigations have observed no significant difference in mean lags measured using these two retinoscopy techniques.[20,34] Thus, the increased lag observed at 40 years of age may have been a result of this lens-induced reduction in accommodation. Nott retinoscopy is the optimal technique for assessing the power of the eye, since it does not require the use of supplementary lenses. Unfortunately, this technique is not practical for older observers, since the target would have to be placed further away to enable them to see it clearly. Further, the longer working distance is less convenient for the retinoscopist in terms of being able to change the lenses easily and may make observation of the reflex more difficult. Nevertheless, the switching of measurement techniques at 40 years of age does not account for the marked increase in lag observed between 40 and 60 years of age (see Figure 1).

The results presented here clearly demonstrate that for the population tested, clinical presbyopia, as indicated by an increase in the lag of accommodation to a 2.50D target, begins at 40 years of age and is complete by 54 years of age. Prior to 40 years of age, the mean expected lag of accommodation to this stimulus demand is 0.50D, with a normal range between 0 and 1.00D. In addition, the results confirm that dynamic retinoscopy is a quick and simple method for determining the lag of accommodation in the clinical setting.

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