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Comparison of the Amplitude of Accommodation Measured Using Push-up, Minus Lens-to-Blur Methods and Hofstetter's Equations in Saudi University Students

Basal Hamad Altoaimi

Department of Optometry, College of Applied Medical Sciences, King Saud University, Riyadh, Saudi Arabia

Email address:
baltoaimi@ksu.edu.sa

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Abstract: *Background*: Commonly, two clinical techniques are used to measure the amplitude of accommodation: push-up and minus lens-to-blur approaches. However, there is no consensus on the accurate technique for assessing the accommodative amplitude in the clinical eye examination. *Aim*: This study was to compare push-up and minus lens-to-blur methods and Hofstetter's equations for assessing the amplitude of accommodation in Saudi university students. *Methods*: This was a comparative cross-sectional, performed in the department of optometry clinic between February and May 2020. The amplitude of accommodation was assessed on 79 Saudi young students (62 males and 17 females, mean age and standard deviation was 23.50 ± 2.29 years old using the push-up and minus lens-to-blur methods and calculated using Hofstetter's equations. *Results:* The findings showed that the highest mean of the amplitude of accommodation was found by using the Hofstetter's maximum equation (15.2 ± 0.9D), whereas the minus lens-to-blur technique provided the lowest result (8.6 ± 1.6D). Using the t-test, significant changes were seen between all methods $P<0.0001$ except the minus lens-to-blur method and Hofstetter's minimum equation $P=0.077$. Measurements by different methods revealed an opposite association between subjects' age and amplitude of accommodation. *Conclusion:* Given the significant variance in results obtained between the different techniques for measuring the amplitude of accommodation, caution should be taken once making decisions regarding amplitude accommodation assessment in young subjects with accommodative disorders and binocular vision abnormalities.

Keywords: Amplitude of Accommodation, Minus Lens-to-Blur, Push-up, Hofstetter's Equation, Optometrists, Diopter

1. Introduction

Accommodation is an increase in the eye's refractive power due to altering the curvature of the crystalline lens for focusing near objects on the retina [1, 2]. An increase in the eye's power happens due to an increase in the anterior and posterior curvatures of the crystalline lens after the contraction of the ciliary muscle innervated by the third carnal nerve (oculomotor nerve) [3-5]. The radius of curvature of the anterior surface of the crystalline lens decreases by 0.33 mm per dioptre of accommodation, whereas the posterior surface decreases by 0.15 mm per diopter of accommodation [6].

The maximum accommodation induced by an eye to see distinctly near an object is called the amplitude of accommodation (AA). It is commonly assessed as the dioptric power corresponding to the near distance to the eye that target could be seen single and clear [1, 7]. For many eye care professionals such as optometrists and ophthalmologists, the measurement of AA is part of the routine eye examination. It is also crucial when evaluating the onset, development, and management of presbyopia and binocular vision problems [8-10].

Previously published studies [9, 11, 12] have revealed that the AA reduces through life in a curvilinear mode from 5 to 50 years of age; the amplitude of accommodation gradually declines at a rate of 0.30 D/year, with the most significant change occurring between 20 and 50 years [13]. Several methods have been developed to assess the AA, including objective procedures such as dynamic retinoscopy and an open-field autorefractor and subjective techniques, such as push-up and minus lens-to-blur [13-15]. Commonly, two clinical techniques have been used to assess AA: the push-up and minus lens-to-blur approaches. However, there is no agreement on the accurate method for measuring the AA in the clinical eye examination [7, 16]. There is an alternative objective method using the equations derived by Hofstetter to calculate AA based on data that was reviewed in 1950. Hofstetter mentioned three equations for calculating maximum, minimum, and average AA [17].

Push-up and minus lens-to-blur methods depend on examiner experience and patient cooperation, but they can detect abnormal accommodation, such as those with abnormal binocular vision. However, Hofstetter's equations do not provide such information. Given the paucity of studies conducted among young Saudi university students to assess methods for measuring AA. Thus, the purpose of this study was to compare measured AA using push-up and minus lens-to-blur methods and calculated Hofstetter's equations in Saudi university students.

2. Methods

2.1. Study Design

The study was a comparative cross-sectional performed in the optometry clinic at the university between February and May 2020.

2.2. Sample

The sample included 62 males and 17 females ranging in age from 19 to 30 years old and mean and standard deviation of 23.50 ± 2.29. The mean and standard deviation of right and left spherical equivalent were (-0.53 ± 1.43D), and (-0.52 ± 1.29D), respectively. Measurements of the AA were obtained from 79 Saudi university students who met the study's inclusion criteria.

2.3. The Inclusion and Exclusion Criteria

The inclusion criteria for the study were subjects who agreed to participate in the study and who signed the consent form. Visual Acuity (VA) 6/6 in both eyes with correction (if existed) with no strabismus, amblyopia, ocular pathology, corneal trauma, and not using treatments affects accommodation. However, the study excluded subjects with worse VA than 6/6, accommodative disorders, binocular vision anomalies, corneal refractive surgery, and systemic disease (e.g., hypertension, diabetes).

2.4. Ethical Considerations

The study was done according to the Declaration of Helsinki rules and was approved by the Institutional review board at King Saud University. Informed consent was obtained from all subjects, and the purpose of the study was explained to them.

2.5. Data Collection Procedures

Before measuring the amplitude of accommodation, demographic information was gathered from the subjects, followed by an examination of VA at near and distance. Objective refraction of the subjects was assessed using retinoscopy (NeitzRX, Japan) and then refined with the subjective refraction, which included the best vision sphere, Jackson cross-cylinder technique, and binocular balanced using the alternate occlusion [18]. The subjects with refractive errors were given their best vision correction and wore it during all AA measurements. AA was measured monocularly (right eye) using two subjective methods (minus lens-to-blur and push-up) and calculated using Hofstetter's equations. The testing sequence was randomized for all subjects.

A pilot study was done on 10 subjects not included in the current study sample. Measurements were performed using all three procedures by a single examiner to assess tests' repeatability. The three methods are described separately below.

2.5.1. Push-up Method

This is the simplest technique for measuring AA, by using a Royal air force (RAF) ruler [20]. In this method, the subjects should wear their full distance correction, then the target (line of letters) is moved towards until the blur of the objective is reported by the subject [20-22]. First, the left eye was covered, the subject's right eye was focused on 20/20 lines of letters on the near reading Snellen chart at a distance of 40 cm. In the current study, the subjects were advised to report when letters became blurred. Then, the target was slowly moved at a rate of 5 cm/s towards the subject's eye until the blur of the letters was reported by the subject. Once the subjects reported the blur, the distance between the subject's eye and the target is recorded and converted to diopter. The measurements were repeated three times for the right eye, and the average value was recorded.

2.5.2. Minus Lens-to-Blur Method

In this method, the subject's best correction was placed into the refractive unit (phoropter), and the test was done monocularly. A target was placed at 40 cm, and the subject was instructed to fixate at the target to a stimulus 2.50 D of accommodation. Then, accommodation was stimulated by adding a series of trial lenses in -0.25 D increments over the subject's distance prescription if it existed. The subject was questioned to inform once the target became blurred as the examiner increased the magnitude of minus lenses. The amplitude of accommodation was recorded as 2.50 D (the dioptric equal of distance 40 cm) with the addition of the amount of minus lens power, ignoring the minus sign [23, 24].

2.5.3. Hofstetter's Equations

Hofstetter used formulae to predicate the AA, based on data reviewed in 1950, and derived three equations for calculating the minimum, average, and maximum predictable amplitude of accommodation for a subject given the age in years [1, 17].

$$\text{Maxiumum AA} = 25 - (0.4 \text{ x Age})$$

$$\text{Average AA} = 18.50 - (0.3 \text{ x Age})$$

$$\text{Minimum AA} = 15 - (0.25 \text{ x Age})$$

This study assessed the maximum, average, and minimum amplitude of accommodation for each subject using Hofstetter's Equations.

2.6. Data Analysis

The data were entered into an Excel sheet, and descriptive analysis was done using SPSS version 24 (Inc., Chicago, IL, United States) and Excel. Paired t-tests and correlation analysis were used to compare the mean findings from the push-up, minus lens-to-blur, and measured minimum, average, and maximum AA by Hofstetter's equation. In this study for ordinal data, Wilcoxon tests were performed with $p < 0.05$ considered statistically significant.

3. Results

A total of 79 subjects aged between 19 to 30 years were comprised in the present study, with a mean age of 23.50 ± 2.29 years who met the inclusion criteria. Based on subjective refraction, the mean and standard deviation of the spherical equivalent of the right eyes was -0.53 ± 1.43 D, and subjects were categorized according to the spherical refractive equivalent as 50 emmetropic (-0.25 to +0.50 D), 25 myopic (≤ -0.50 D), and 4 hyperopic (≥ +0.50 D). From the 79 students, 62 (78.5%) were males and 17 (21.5%) females. There was an insignificant variance between the mean ages of the males and females (p = 0.761).

Table 1 showed the descriptive analysis for the amplitude of accommodation measurements by different methods. The Shapiro–Wilk test revealed that the measurements of the amplitude of accommodation were distributed normally with a p > 0.05. All the measurements were taken for the right eyes only, the means amplitude of accommodation ranged from 8.6 (95% CI, 8.2–9.1) D to 15.2 (95% CI, 15.0–15.7) D; the Hofstetter's maximum had the highest average, while the minus lens-to-blur method had the lowest average.

Table 1. *Descriptive statistics of the measurements of the amplitude of accommodation using the push-up, minus lens, and Hofstetter's equations.*

Statistics	**Push-up (95% CI)**	**Minus lens (95% CI)**	**HOF AVE (95% CI)**	**HOF MAX (95% CI)**	**HOF MIN (95% CI)**
Means	9.4 (9.0- 9.7)	8.6 (8.2- 9.1)	11.2 (11.0- 11.3)	15.2 (15.0- 15.7)	8.9 (8.8- 9.2)
Standard deviations	1.3 (1.3- 1.9)	1.6 (1.28- 1.87)	0.65 (.53- 0.75)	0.9 (0.7- 1.0)	0.5 (.45- 0.63)
Skewness	0.32 (-.76-.29)	0.6 (-.18- 1.1)	-0.72 (-1.1- -0.25)	-0.8 (-1.2- -0.34)	-0.7 (-1.1-- 0.19)
Kurtosis	0.39 (-.64- 1.5)	1.0 (-.56- 2.45)	0.5 (-0.54- 2.0)	0.49 (-0.56- 2.12)	0.43 (-0.57- 1.9)
Variance	2.7 (1.77- 3.5)	2.6 (1.65- 3.5)	0.43 (0.5- 1.0)	0.75 (0.5- 1.0)	0.3 (0.2- 0.39)
Minimums	4.50	5.50	9.20	12.60	7.25
Maximums	12.50	13.75	12.50	16.60	10.00

HOF AVE= Hofstetter's average.
HOF MAX= Hofstetter's maximum.
HOF MIN= Hofstetter's minimum.
Note: The units are in diopters (D).

Table 2. *T-test to determine the difference of the amplitude of accommodation measurements between five different methods.*

Paired procedures	**Mean differences**	**Std. Deviation**	**Std. Error Mean**	**95% Confidence Interval of the Difference**		**P-value**
				Lower	**Upper**	
Push-up and Minus lens	0.83	1.35	0.15	0.52	1.12	0.00
Push-up and HOF AVE	-1.80	1.96	0.22	-2.24	-1.36	0.00
Push-up and HOF MAX	-5.85	1.78	0.20	-6.25	-5.45	0.00
Push-up and HOF MIN	0.49	1.67	0.19	0.11	0.86	.011
Minus lens and HOF AVE	-2.63	2.00	0.23	-3.08	-2.19	0.00
Minus lens and HOF MAX	-6.68	1.80	0.20	-7.08	-6.27	0.00
Minus lens and HOF MIN	-0.34	1.68	0.19	-0.71	0.04	0.077
HOF AVE and HOF MAX	-4.05	0.21	0.02	-4.09	-4.01	0.00
HOF AVE and HOF MIN	2.29	0.14	0.02	2.23	2.32	0.00
HOF MAX and HOF MIN	6.34	0.33	0.04	6.27	6.41	0.00

Table 2 shows the mean difference, standard deviations, standard error of the mean, 95% confidence intervals difference, and p-value for paired comparisons of the five techniques. The T-test was used to assess the difference in the average amplitude of accommodation measurements of the different techniques.

The T-test showed that the highest mean difference was between the minus lens and Hofstetter's maximum (-6.68 D), Hofstetter's maximum and Hofstetter's minimum (6.34 D), push-up and Hofstetter's maximum (-5.85 D), minus lens-to-blur and Hofstetter's average (-2.63 D), and Hofstetter's average and Hofstetter's minimum (2.29 D). The results obtained using the Hofstetter's maximum and Hofstetter's average equation were higher than those obtained using the push-up and minus lens-to-blur methods. However, the results obtained by minus lens-to-blur were comparable to those found by Hofstetter's minimum p=0.077. An analysis using the t-test among all pairs revealed a statistically significant difference except between the minus lens-to-blur and Hofstetter's minimum methods. as shown in tables 1 and 2.

Figure 1 The whisker plot shows the distributions of the amplitude of accommodation measurements by different methods push-up, minus lens-to-blur, and Hofstetter's equations. The mean markers, and mean line of the amplitude of accommodation by push-up, minus lens-to-blur, and Hofstetter's minimum were below 10.00 D. In contrast, Hofstetter's maximum and Hofstetter's average measurements were more than 10.00 D.

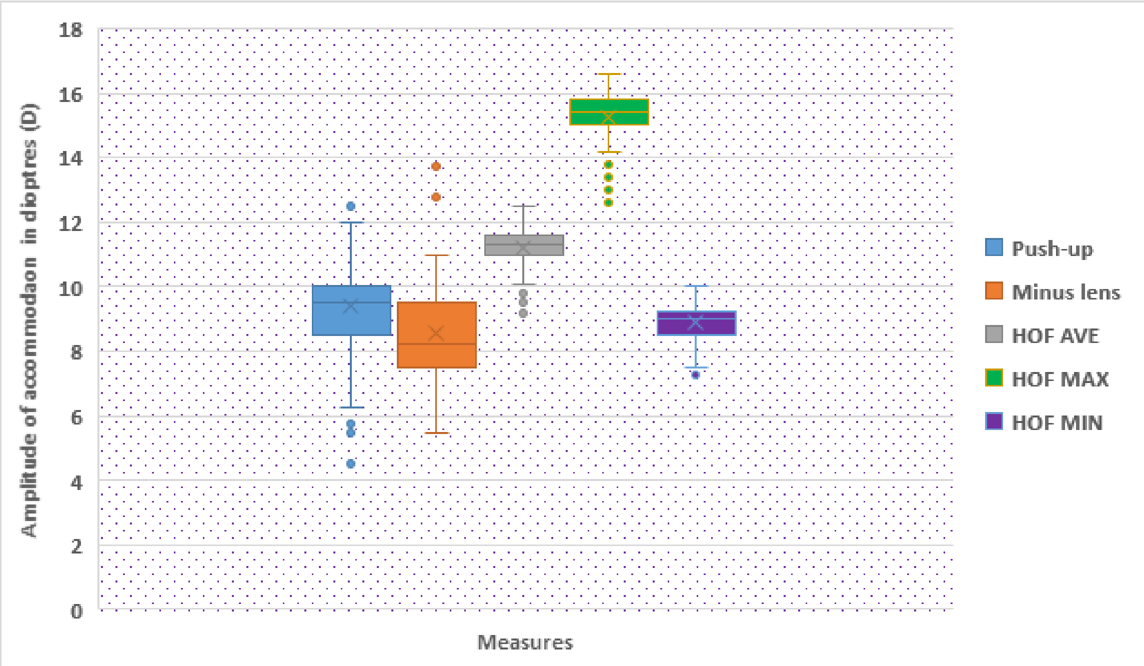

Figure 1. *Box plots display the amplitude of accommodation measured by different methods push-up and minus lens-to-blur and Hofstetter's equations. The box plots show outlier points, mean markers, and mean line of the amplitude of accommodation measurements.*

Figure 2 Scatter plots showed the amplitude of accommodation measured by different methods through ages from 19 to 30 years. The results revealed an opposite association between subject age and amplitude of Accommodation, in which the amplitude of accommodation measurements decreased as age increased. As shown in Figure 2, the measures of the accommodative amplitude using push-up and minus lens-to-blur techniques are laid under the mean values generated using Hofstetter's average equation (solid line).

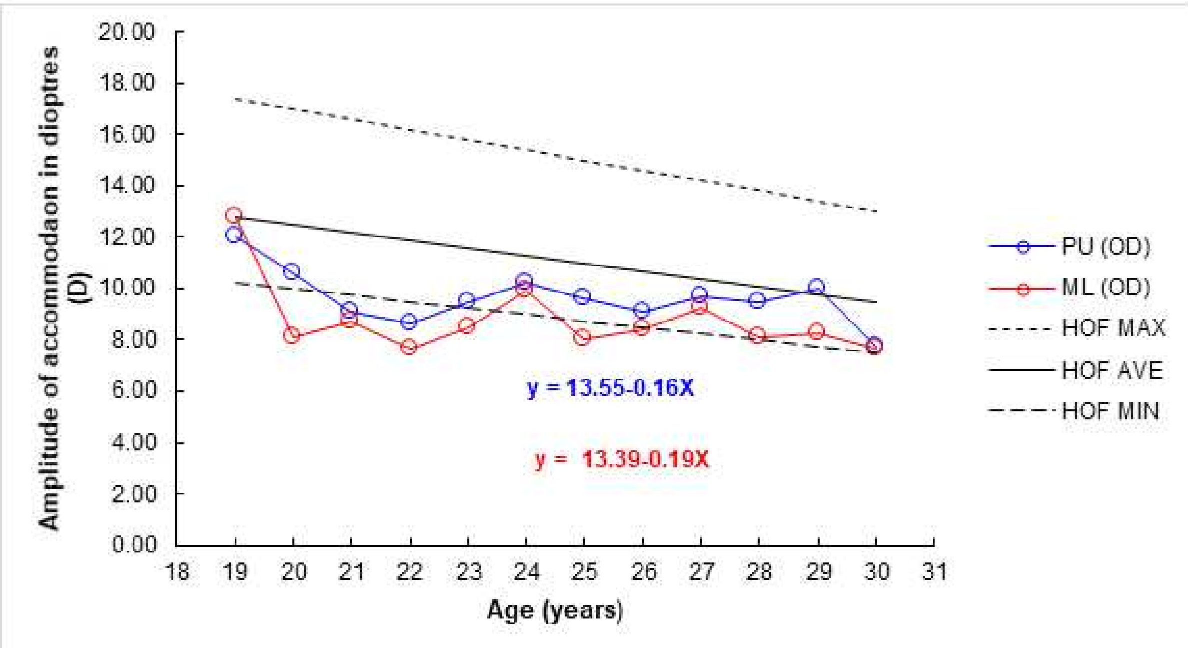

Figure 2. *Scatter plots of the amplitude of accommodation were measured by different methods as a function of the age of the subjects.*

4. Discussion

Assessment of the accommodative amplitude is a recommended element of clinical eye examination worldwide. The detection and management the refractive disorders, including latent hypermetropia, latent strabismus, and presbyopia are normally assisted by determining the AA [25]. Accommodative amplitude is affected by a wide range of physiological and other factors. They include ethnicity, refractive error, adaptation to sunlight, dyslexia, intraocular pressure, diabetes, Down syndrome, and alcohol consumption [26-28]. Therefore, the purpose of the current study was to compare push-up and minus lens-to-blur methods and Hofstetter's equations for determining the AA in Saudi university students.

Hofstetter's maximum and average equations showed a higher mean of AA, followed by the push-up method, while the minus lens-to-blur method revealed the lowest mean of AA. This study showed that AA findings differ significantly between all methods $P<0.0001$ except the minus lens-to-blur method and Hofstetter's minimum equation $P = 0.077$. Measurement of the AA by different methods revealed an inverse relationship between age and AA. These results agreed with preceding studies stated that from 5 to 52 years of age, the amplitude of accommodation gradually decreases at a rate of 0.30 D/year [1-21].

The common clinical techniques to measure the amplitude of accommodation are the push-up and the minus lens-to-blur, and our study showed significantly different measurements between the two methods, where the push-up technique provides a higher mean of the AA. Published studies [2, 16] reported that the push-up method might be suitable for routine clinical assessment of the AA. However, it is not accurate for measuring a true accommodative amplitude as it overestimates the findings [2, 29]. The higher AA findings with the push-up technique compared to the minus lens-to-blur method have been mentioned in many studies [16, 2]. These higher findings of AA attributed to the target size, depth of focus, proximal cues, illumination, end-point criteria, subject variability, and change in pupil size [16, 30]. While measuring the accommodative amplitude by the push-up technique, there is an increase in the size of the retinal image associated with the decline in the objective distance; furthermore, there is stimulation of proximal accommodation, which leads to higher findings compared to minus lens-to-blur methods [20, 30]. Previous studies indicated that illumination could affect the measurements of the AA and recommended that the target have to be illuminated by approximately a 40-watt incandescent bulb. However, the high illumination could significantly increase the depth of focus for some subjects and result in the wrong high amplitude of accommodation findings [16, 20, 30].

As mentioned above, the results of the present study showed the minus lens-to-blur method had the lowest mean of AA compared to the Hofstetter maximum and average equations as well as the push-up method. However, minus lens-to-blur methods give results comparable to that obtained by Hofstetter's minimum equation. This result agrees with the findings from earlier published studies [1, 15, 16]. The low finding for the AA by using the minus lens-to-blur technique could be due to reduction of the quality of the retinal image due to the properties of the higher minus lenses, whereas there is no distance magnification as in push up method, and the proximal stimulus of the accommodation remains unchanged. Push-up and minus lens are subjective methods for assessing amplitude of accommodation measurement, has many factors that affect their accuracy [25].

From the findings of the current study, it could be concluded that the accommodative amplitude measurements obtained by push-up and minus lens-to-blur methods for Saudi students aged 19 to 30 years are dissimilar from the predictable values by using Hofstetter's equation for maximum and average and comparable to the minimum expected values. Many authors [1, 31-33] have raised apprehensions about using values obtained from Hofstetter's calculations as a standard, particularly in young adults, to estimate the amplitude of accommodation. They reported that Hofstetter's equations were derived from data of old age people; about 35 out of the approximately 1,000 persons were youngsters. Therefore, these equations might not be usable for expecting the amplitude of accommodation for children. In addition to the inhabitants from which Hofstetter's equations were derivative from the Caucasian population, this has also been a disadvantage in using the equations for other ethnicities. The drawback of Hofstadter's equations did not base on the patient's response, so it was difficult to differentiate between normal and abnormal accommodative responses [16].

The present study has limitations. The study was cross-sectional and included only normal and healthy young students. Subjects with ocular symptoms, amblyopia, or who underwent refractive surgery did not participate in the study, and the findings from such groups may have been different from the current results. Minus lens-to-blur method takes a longer time to achieve, and the precision of the measurements could vary with the practitioner's skills. Despite the limitations mentioned, the present study provides information about the variation of measurements of the accommodative amplitude by using different methods.

5. Conclusion

In comparison to the push-up method, Hofstetter's maximum and average equations overestimate the accommodative amplitude, whereas the minus lens-to-blur technique gives an underestimate of AA because creates an abnormal seeing situation in which the object is fixed but the stimulus becomes progressively minified. Given the significant variance in results obtained between the different techniques for measuring the amplitude of accommodation, caution should be taken once making decisions regarding amplitude accommodation assessment in young subjects with accommodative disorders and binocular vision abnormalities.

Conflicts of Interest

The authors declare no conflicts of interest.

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