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Emmanuel Kwasi Abu
University of Cape Coast

Stephen Ocansey
University of Cape Coast

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Comparing Different Methods of Measuring Accommodative Amplitude with Hofstetter's Normative Values in a Ghanaian Population

Emmanuel K Abu[a], Stephen Ocansey[a,b], Joseph Yennu[a], Isaac Asirifi[a], and Richmond Marfo[a]

[a]Department of Optometry, School of Allied Health Sciences, University of Cape Coast, Cape Coast, Ghana; [b]Department of Vision and Hearing Sciences, Faculty of Science and Technology, Anglia Ruskin University, Cambridge, United Kingdom

ABSTRACT

Aim: Amplitude of accommodation (AoA) can be determined clinically using different methods. Some methods are known to be more reliable than others for measuring AoA in different age categories. The purpose of this study was to compare Hofstetter's age-expected norms with five recommended methods of measuring AoA in order to determine age-appropriate techniques for a Ghanaian population.

Materials and methods: AoA was measured using four subjective methods (push-up, push-down, minus lens, and modified push-up) and one objective method, the modified dynamic retinoscopy. The amplitudes obtained by each technique were compared to each other and also compared to the age-expected amplitudes as predicted by Hofstetter's equations.

Results: 352 non-presbyopes aged 10–39 years were included in this study. All five methods except the push-up (p = 0.089) and modified push-up (p = 0.081) differed significantly from Hofstetter's data, while the modified dynamic retinoscopy recorded the strongest agreement with Hofstetter's average (ICC = 0.78, p < 0.001). With reference to Hofstetter's expected AoA, the minus lens, push-down, modified dynamic retinoscopy, and modified push-up methods underestimated AoA by −4.18D, −1.99D, −0.48D, and −0.43D, respectively. As age increased, underestimated AoA values by the minus lens (10–19 years: −5.57D, 20–29 years: −3.50D, 30–39 years: −2.39D), modified push-up (10–19 years: −1.51D, 20–29 years: +0.40D, 30–39 years: +0.56D), and push-down (10–19 years: −2.90D, 20–29 years: −1.07D, 30–39 years: −1.46D) methods decreased but the modified push-up in relation to Hofstetter's expected was most accurate for the older age. The push-up, on the other hand, overestimated accommodation in all age categories by +0.42D (10–19 years: +0.01D, 20–29 years: +0.82D, 30–39 years: 0.67D). Thus, the push-up method became more accurate as age decreased.

Conclusion: This study suggested that Hofstetter's formulae could be used to predict the amplitudes of Ghanaian non-presbyopes aged 10–39 years using the push-up and modified push-up. With regard to Hofstetter's data, the push-up method was more accurate for the younger age-group 10–19 years while the modified push-up was more accurate for the older age-group 20–39.

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Introduction

Amplitude of accommodation (AoA) is the maximum amount of dioptric power the eye can exert for images of objects within finite distance to be brought to focus on the retina. Clinical assessment of AoA forms an integral basis for the diagnosis and management of accommodative dysfunctions.[1] This is achieved through the comparison of measured and calculated age-expected normative values.

Clinical measurement of AoA could be obtained through independent subjective methods such as push-up, push-down (or push-away), minus lens, and modified push-up. Modifying the traditional dynamic retinoscopy method can be used to obtain an objective estimate of AoA.[2] The use of the open field autorefractometry also gives an objective determination of AoA; but this equipment is not widely available to the general eye care practitioner outside research laboratories. The different subjective methods of measuring AoA come with several measurement errors such as, depth of focus, reaction time, anomalous proximal cues, and practitioner bias.[2] Consequently, depending on which method is employed clinically, different results are produced, and therefore one method cannot conveniently be substituted for another. Relatively, while some methods are reported to overestimate AoA values, others underestimate. There is no specific recommended gold standard test of measuring AoA but often the choice of a particular method depends on the ease of procedure, examiner preference, and the availability of equipment. The push-up method appears to be the simplest and hence, the most commonly used clinical technique to measure accommodative amplitude.[2,3]

To diagnose accommodative dysfunctions (especially insufficiency and excess), age-expected AoA is calculated using Hofstetter's equations derived from earlier works by Donders[4] and Duane.[5] Hofstetter analyzed the AoA values that Donders and Duane had measured from their subjects and derived three equations for determining the minimum, average, and

CONTACT Emmanuel K Abu eabu@ucc.edu.gh Department of Optometry, University of Cape Coast, PMB, Cape Coast, Ghana
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maximum age expected normative AoA data for an individual. Both Donders and Duane measured AoA in their subjects using slight variations of the subjective push-up method. Donders measured accommodation using 130 participants between the ages of 10 years and 80 years. Duane measured AoA in over 4000 eyes of participants aged 8–72 years of which only 35 were children. Hofstetter[6] used a linear fit for the pooled data of Donders and Duane from 8 years to 80 years, and therefore his expected norms for children below 8 years were based on extrapolation. Many concerns have been raised about the studies of Donders and Duane regarding design limitations. However, Hofstetter's formulae continue to be useful in the diagnosis and management of accommodative anomalies.

There have been several reported variations between measured and calculated AoA values across different populations. These variations have been attributed to physiological and geographical factors including climate,[7] race,[7] education,[8] ambient temperature,[9] and intraocular pressure.[10] The literature also suggests that intra and inter variations between measured and calculated AoA results are attributable to age differences and that certain methods may be more suitable than others for measuring AoA as a function of age. Taub et al.,[11] for instance, reported that in American adults the push-away method varied significantly from Hofstetter's normative data, but in children there was no significant difference between the two results. No previous studies have recommended age-specific techniques for AoA measurements. The present study reinforces the argument that it may be necessary to recommend age-specific methods to measure AoA in clinical settings and perhaps for different populations as well.

Clinical parameters for diagnosing accommodative anomalies include AoA, relative accommodation (positive and negative), lead or lag of accommodation using the monocular estimate method (MEM), and accommodative facility using plus and minus flipper lenses. The present study compared Hofstetter's objective predicted AoA with measured AoA because of the continued use of AoA as a common parameter for diagnosing accommodative deficits in Ghanaians (Ovenseri-Ogbomo et al., 2012),[12] and the clinical significance of Hofstetter's age-expected normative data for diagnosis and treatment of accommodative anomalies.[1] For instance, one of the criteria for accommodative insufficiency is a push-up AoA of at least 2D below Hofstetter's minimum age-appropriate amplitude.[13] Investigations involving different AoA tests on different age-groups compared to Hofstetter's age-expected values will further help our understanding of the link between expected and measured values.

The purpose of this study was therefore to compare Hofstetter's age-expected values with five recommended methods of measuring AoA in a wide age range (10–39 years) of Ghanaian non-presbyopes. This will be helpful in determining age-appropriate AoA measurement techniques to guide diagnosis and management of accommodative anomalies in different age-groups of our population.

Materials and methods

This study was carried out among school pupils/students and teachers in the Cape Coast Metropolis in the Central Region of Ghana. The study participants included basic school pupils (10–14 years), senior high school students (15–17 years), tertiary students (18–24 years), and teachers (25–39 years). The Cape Coast Metropolis is divided into six educational circuits. One basic and one senior high school were randomly selected from each educational circuit, from which all the pupils and students who met the inclusion criteria were examined. Tertiary students were randomly selected from the two tertiary institutions in the Cape Coast Metropolis, namely the University of Cape Coast and the Cape Coast Technical University. Teachers within the selected basic and senior high schools who were non-presbyopes were also selected into the study.

The inclusion criteria were that the participants had: refractive error less than ±3.00 diopter sphere or −3.00 diopter cylinder, best corrected visual acuity of 0.00 logMAR (Snellen equivalent of 6/6) or better in each eye at both distance and near, no obvious deviation at both distance and near, MEM retinoscopy within +0.25 to +0.75D, and no history of ocular trauma, ocular pathology, amblyopia, or aphakia.[12] Significant refractive error was excluded because of its impact on accommodation. Early presbyopes were also excluded from participating in this study.

All participants underwent ophthalmic examination comprising visual acuity using the logMAR chart at 4 m for distance and 40 cm for near, AoA measurement, cover test, external eye examination with a handheld slit lamp, and internal ocular examination with direct undilated ophthalmoscopy. Non cycloplegic static retinoscopy as done by previous studies[3,11,12,14–16] and distance subjective refraction were performed on participants. The resultant refractive correction was mounted on a trial frame under normal room illumination (250–500 lux) for all measurements of AoA.

All measurements of AoA were done monocularly on the dominant eye with the fellow eye being occluded. The procedures were performed by experienced optometrists who had undertaken similar studies previously. Prior to conducting the procedures, the examiners met and agreed on the criteria that would constitute the end point for each test procedure. The order of carrying out each procedure was randomized and each performed by only one examiner where no examiner knew the other examiners' findings.

AoA was measured using push-up, push-down, minus lens, modified push-up and modified dynamic retinoscopy methods. The Royal Air Force (RAF) near point rule was used for the push-up method. The attention of the individual was directed to the N5 row of letters and the target was slowly moved along the midline while instructing the participant to keep the print clear. Whereas the target was slowly pushed closer, the participant was asked to try and clear the initial observed blur, and the target pushed further closer toward the participant until the blur became sustained. The end point was the point of first sustained blur after two or three seconds of viewing. The distance in meters from this point to the spectacle plane was measured and converted to dioptric power as the push-up amplitude. For the push-down method, the accommodative target on the RAF near point rule was first moved towards the participant to produce a significant blur. The target was then pushed away until the participant could just read clearly the N5 row of letters. The distance from this point to the spectacle plane was measured in meters and converted to diopters.

The modified push-up method was carried out in a similar manner as the push-up technique except that in the modified push-up method, AoA was measured through a −4.00D lens added over the distance correction. The push-up technique was then performed through this lens combination.[14] For the minus lens method, the chart was placed at a viewing distance of 40 cm. After instructing the individual to fixate on the N5 row of letters on the chart, the minus lenses were added in 0.25D steps over the distance correction until the letters became and remained blur. A dioptric value of 2.50D (representing the viewing distance) plus the added minus lens power that produced the blur was recorded as the minus lens amplitude.

A modified dynamic retinoscopy technique described by Rutstein et al.[17] was performed. The participant was asked to fixate on the 6/6 row of letters attached to the retinoscope. While occluding the fellow eye, the individual was asked to read the letters at about 40 cm and keep them clear. With the vertical streak of the retinoscope and noticing a slight with motion, the examiner moved the retinoscope forward to – where a persistent noticeable change in the retinoscope reflex occurred. At this point, the width of the retinoscope reflex became narrower, its color being dimmer and the speed also becoming slower. At this point, the distance was measured and converted to diopters.

Hofstetter's normative amplitudes of accommodation were determined for each participant using the formulae: Minimum AoA = 15–0.25 (age in years), average AoA = 18.5–0.30 (age in years), and maximum AoA = 25–0.40 (age in years).[18] The participants' ages were categorized into three: 10–19, 20–29, and 30–39. This age categorization as in the previous studies was not based on any standardized criterion.

The data collected were analyzed using the SPSS statistical software, version 21. One way analysis of variance (ANOVA) was used to investigate the differences in mean accommodative amplitudes between the various age-groups. A repeated measures of ANOVA was performed to assess the differences in mean amplitudes between the various measurement techniques, using the Bonferroni correction while performing the *post hoc* analysis. Bivariate Pearson Correlation was employed to measure the strength and direction of linear relationships between the various methods of measuring AoA and the intraclass correlation coefficient (ICC) test was done to assess the agreement levels between the various techniques. A $p \leq 0.05$ was considered statistically significant. Parametric statistics were performed with the assumption that the use of a large sample size will compensate for any invalidities that would arise if the data do not fit in a normal distribution.

Ethical approval for the study was obtained from the Institutional Review Board of the University of Cape Coast and ethical clearance certificate with identification number UCCIRB/CHAS/2015/086 was issued. The study was conducted according to the Tenets of the Declaration of Helsinki. Approval to conduct the research in the various schools was also sought from the Cape Coast Regional Education Directorate. Written consent was obtained from the students and teachers. For the pupils and students less than 18 years, after giving verbal assents, their parents/guardians signed the consent forms on their behalf. Participants were told their participation in the study was voluntary and that they could decide to exit or terminate at any point in time.

Results

The total number of participants was 352 with ages ranging from 10 years to 39 years (mean age = 21.38 ± 8.29). The age distribution of participants is shown in Table 1. There were 156 (44.3%) males and 196 (55.7%) females with no significant difference between the mean ages of males and females ($F = 2.5$, $p = 0.11$). The mean amplitudes of the various techniques and Hofstetter's expected values were obtained as shown in Table 1. The highest mean amplitude was recorded with the push-up (12.50 ± 3.30D), followed by the modified push-up (11.65 ± 2.29D), modified dynamic retinoscopy (11.60 ± 3.19D), push-down (10.10 ± 2.60D), and the minus lens method (7.91 ± 1.71D), respectively.

With reference to Hofstetter's calculated average amplitudes of accommodation, the values recorded by the minus lens, push-down, modified dynamic retinoscopy, and modified push-up techniques underestimated accommodation by −4.18D, −1.99D, −0.48D, and −0.43D, respectively. The push-up was the only technique which overestimated accommodation in all age-groups (by +0.42D) and also had the least mean difference between Hofstetter's average value (Table 2). In the 10–19 years age-group, overestimation of accommodation (in relation to Hofstetter's equations) by the push-up method was very minimal (+0.01D) but this began to increase with increasing age (10–19 years: + 0.01D, 20–29 years: +0.82D, 30–39 years: +0.67D). Thus, as age of participants decreased the push-up method became more accurate (it became closer to the calculated average value). On the other hand, underestimated values decreased as age increased. For example, in relation to Hofstetter's calculated average data, underestimation by the minus lens decreased with increasing age as: 10–19 years: −5.57D, 20–29 years: −3.50D, 30–39 years: −2.39D with an average underestimation of −4.18D. The modified push-up underestimated accommodation in the 10–19 age-group by −1.51D but overestimated in the older ages (10–19 years: −1.51D, 20–29 years: +0.40D, 30–39 years: +0.56D). The push-down results decreased inconsistently with increasing age as: 10–19 years: −2.90D, 20–29 years: −1.07D, 30–39 years: −1.46D. Results from the modified dynamic retinoscopy were inconsistent with changes in age of participants (10–19 years: −1.04D, 20–29 years: +0.57D, 30–39 years: −0.81D). Thus, the minus lens and modified push-up methods became more accurate as age of participants increased. However, the modified push-up method was most accurate for the older age as the minus lens underestimated as much as −2.39D in the 30–39 year age-group which differed significantly from Hofstetter's data. Figure 1 represents a scatter plot of the AoA as a function of the age using a polynomial fit for all measured AoA and Hofstetter's average.

Table 2 compares the mean differences and the levels of agreements between all the measured and age-expected AoA values. By repeated measures of ANOVA, the pairwise comparisons between all the techniques indicated that all the five

Table 1. Means of amplitude of accommodation values recorded with the various techniques.

Age (mean ± SD)	*n* (%)		Measurement technique of AoA					Hofstetter's calculated AoA		
			PU	PD	ML	MPU	MDR	Max	Ave	Min
10–19 (14.2 ± 2.7)	160 (46)	Mean ± SD	14.25 ± 3.33	11.34 ± 2.26	8.67 ± 1.35	12.73 ± 2.72	13.20 ± 2.17	19.32 ± 1.11	14.24 ± 0.82	11.44 ± 0.68
		CI	13.73 – 14.77	10.99 – 11.70	8.46 – 8.88	12.31 – 13.16	12.86 – 13.53	19.15 – 19.49	14.11 – 14.39	11.33–11.54
20–29 (22.2 ± 2.0)	110 (31)	Mean ± SD	12.62 ± 1.81	10.73 ± 1.62	8.30 ± 1.49	12.20 ± 2.44	12.37 ± 2.57	16.06 ± 0.81	11.80 ± 0.60	9.41 ± 0.50
		CI	12.28 – 12.96	10.43 – 11.04	8.02 – 8.58	11.73 – 12.66	11.89 – 12.86	15.91–16.21	11.68 – 11.91	9.31–9.50
30–39 (34.1 ± 3.2)	82 (23)	Mean ± SD	8.94 ± 1.50	6.81 ± 1.07	5.88 ± 0.78	8.83 ± 1.92	7.46 ± 1.66	11.36 ± 1.28	8.27 ± 1.00	6.48 ± 0.80
		CI	8.61 – 9.27	6.58 – 7.05	5.71 – 6.05	8.41 – 9.25	7.09 – 7.82	11.08 – 11.64	8.06 – 8.48	6.30 – 6.65
Total	352		12.50 ± 3.30	10.10 ± 2.60	7.91 ± 1.71	11.65 ± 2.29	11.60 ± 3.19	16.44 ± 3.31	12.09 ± 2.48	9.65 ± 2.06
p-value			<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

AoA: amplitude of accommodation, SD: standard deviations, CI: confidence interval, PU: push-up, PD: push-down, ML: minus lens, MDR: modified dynamic retinoscopy, MPU: modified push-up, Max: maximum, Ave: average, Min: minimum.

measured values except those of the push-up ($p = 0.089$) and the modified push-up ($p = 0.081$) differed significantly from Hofstetter's predicted average values. All four subjective methods also differed significantly from each other. Again, the objective method (modified dynamic retinoscopy) varied significantly from all the subjective methods except the modified push-up ($p > 0.99$).

By Bivariate Pearson Correlation analysis, Hofstetter's expected values (maximum, average, and minimum) recorded perfectly strong positive correlations between each other ($r = 1.00$, $p < 0.001$). Between the other methods, the strongest correlation was recorded between push-up and push-down methods ($r = 0.74$, $p < 0.001$). With the ICC test between all the five methods as represented in Table 2, the strongest agreement was found between the push-up and modified push-up (ICC = 0.77, $p < 0.001$), followed by the push-up and the modified dynamic retinoscopy (ICC = 0.71, $p < 0.001$), and then between the push-up and the push-down (ICC = 0.70, $p < 0.001$). Between the objective (modified dynamic retinoscopy) and the subjective methods, a strong agreement (ICC = 0.71, $p < 0.001$) was found between the push-up and a moderate agreement between the modified push-up and the push-down methods (Table 2). Between Hofstetter's calculated average amplitude and all measured values, a strong agreement was between the objective method (modified dynamic retinoscopy) (ICC = 0.78, $p < 0.001$) and the push-up method (ICC = 0.74, $p < 0.001$). There were moderate agreements between Hofstetter's average and the push-down (ICC = 0.69, $p < 0.001$), and modified push-up methods (ICC = 0.67, $p < 0.001$). The minus lens method did not show agreement with any of the methods except the push-down which only agreed with it moderately.

Discussion

The clinical measurement of AoA could be achieved by several methods. In this study, five methods of which four were subjective and one objective were employed to measure AoA in a wide age range. We compared Hofstetter's objective predicted AoA with measured AoA values because of their continued use as important clinical parameters for diagnosis and treatment of accommodative anomalies in our population.

The order of accommodative values obtained with the various methods in the current study is similar to that reported by Momeni-Moghaddam et al.,[14] where the push-up had the highest and minus lens had the least values. The least AoA values recorded by the minus lens in this study are also similar to previous studies.[11,14,19,20] On the contrary, León et al.[15] by comparing the push-down, minus lens, and the dynamic retinoscopy methods in a Colombian population recorded the least amplitudes with the dynamic retinoscopy method. The differences in the procedure of the dynamic retinoscopy method may have accounted for the differences in the results.

Contrary to studies by Ovenseri et al., in both Ghanaian[12] and Nigerian[16] children, the current study found no significant differences between the push-up result and Hofstetter's calculated average values (mean difference = 0.42, $p = 0.089$). The age differences between the participants of these studies

Table 2. Mean differences, Pearson's correlation (*r*), and intraclass correlation coefficient (ICC) between all the techniques and Hofstetter's expected values.

Methods			Mean difference (95% CI)	Bonferroni *p*-value	*r* (*p*-value)	ICC (95% CI)	*p*-value
PU	Versus	PD	+2.41 (2.03 to 2.78)	0.000	0.738 (<0.001)	0.70 (−0.01–0.87)	<0.001
		ML	+4.60 (4.14 to 5.05)	0.000	0.575 (<0.001)	0.31 (−0.19–0.63)	<0.001
		MPU	+0.85 (0.41 to 1.28)	0.000	0.659 (<0.001)	0.77 (0.70–0.83)	<0.001
		MDR	+0.90 (0.40 to 1.41)	0.000	0.569 (<0.001)	0.71 (0.62–0.77)	<0.001
		HOF MAX	−3.95 (−44.3 to −34.6)	0.000	0.619 (<0.001)	0.53 (−0.20–0.79)	<0.001
		HOF AVE	**+0.42 (−0.25 to 0.86)**	**0.089***	0.619 (<0.001)	0.74 (0.68–0.79)	<0.001
		HOFMIN	+2.86 (2.42 to 3.29)	0.000	0.619 (<0.001)	0.53 (−0.11–0.77)	<0.001
PD	Versus	ML	+2.19 (1.84 to 2.55)	0.000	0.587 (<0.001)	0.53 (−0.08–0.76)	<0.001
		MPU	−1.56 (−1.97 to −1.15)	0.000	0.618 (<0.001)	0.69 (0.41–0.82)	<0.001
		MDR	−1.51 (−1.95 to −1.06)	0.000	0.592 (<0.001)	0.68 (0.45–0.79)	<0.001
		HOF MAX	−6.35 (−6.76 to −5.94)	0.000	0.681 (<0.001)	0.34 (−0.13–0.69)	<0.001
		HOF AVE	−1.99 (−2.33 to −1.65)	0.000	0.681 (<0.001)	0.69 (0.07–0.86)	<0.001
		HOF MIN	+0.45 (0.13 to 0.77)	0.000	0.680 (<0.001)	0.79 (0.73–0.83)	<0.001
ML	Versus	MPU	−3.75 (−4.16 to −3.34)	0.000	0.549 (<0.001)	0.35 (−0.20–0.66)	<0.001
		MDR	−3.70 (−4.12 to −3.27)	0.000	0.608 (<0.001)	0.40 (−0.20–0.69)	<0.001
		HOF MAX	−8.54 (−8.98 to −8.11)	0.000	0.643 (<0.001)	0.15 (−0.08–0.45)	<0.001
		HOF AVE	−4.18 (−4, 50 to −3.86)	0.000	0.642 (<0.001)	0.34 (−0.16–0.68)	<0.001
		HOF MIN	−1.74 (−2.01 to −1.47)	0.000	0.643 (<0.001)	0.62 (0.06–0.82)	<0.001
MPU	Versus	**MDR**	**+0.05 (−0.45 to 0.56)**	**1.000***	0.517 (<0.001)	0.68 (0.61–0.74)	<0.001
		HOF MAX	−4.79 (−5.31 to −427)	0.000	0.510 (<0.001)	0.38 (−0.20–0.68)	<0.001
		HOF AVE	**−0.43 (−0.89 to** −0.02)	**0.081***	0.510 (<0.001)	0.66 (0.59–0.73)	<0.001
		HOF MIN	+2.01 (1.54 to 2.44)	0.000	0.509 (<0.001)	0.54 (0.12–0.73)	<0.001
MDR	Versus	HOFMAX	−4.85 (−5.2 to −4.41)	0.000	0.673 (<0.001)	0.48 (−0.20–0.79)	<0.001
		HOF AVE	−0.48 (−8.88 to −0.08)	0.005	0.673 (<0.001)	0.78 (0.73–0.83)	<0.001
		HOF MIN	+1.96 (1.56 to 2.35)	0.000	0.673 (<0.001)	0.65 (0.18–0.82)	<0.001
HOF MAX	Versus	HOF AVE	+4.36 (4.22 to 4.50)	0.000	1.000 (<0.001)	0.63 (−0.03–0.89)	<0.001
		HOF MIN	+6.80 (6.59 to 7.01)	0.000	0.999 (<0.001)	0.36 (−0.03–0.74)	<0.001
HOF AVE	Versus	HOF MIN	+2.44 (2.37 to 2.51)	0.000	0.999 (<0.001)	0.77 (−0.03–0.94)	<0.001

CI = confidence interval, *r* = correlation coefficient, ICC = intraclass correlation coefficient, PU: push-up, PD: push-down, ML: minus lens, MDR: modified dynamic retinoscopy, MPU: modified push-up, HOF MAX: Hofstetter's maximum, HOF AVE: Hofstetter's average, HOF MIN: Hofstetter's minimum.
*Insignificant level of association found.

seem to account for the inconsistencies. For instance, the mean ages of the participants in the two earlier studies by Ovenseri et al. were 11.1 and 11.6 years, respectively, while this study had a mean age of 21.4 years. Ovenseri et al.[12,16] had concluded from their findings that the push-up method failed to accurately account for the age-expected norms for the accommodative amplitudes calculated from Hofstetter's equation. In this study among older children and adults, however, we found that Hofstetter's equation was applicable using the push-up and modified push-up methods. Ovenseri et al.[12,16] recorded higher differences between Hofstetter's data and the push-up for the younger children from 6 years but toward age 10 years, the differences became minimal but the overall difference was significant when compared with Hofstetter's data. Our study found greater differences between the push-up and Hofstetter's data in the higher ages but toward age 10 years, the differences also became minimal. The two methods were therefore similar for ages around 10–14 years. The major factor that seems to account for the differences is age. Similarly, Taub et al.[11] by comparing the push-down with Hofstetter's data in an American population found no significant difference in children ($p = 0.28$) but recorded a significant difference in adults ($p = 0.03$). They also found the push-up method to overestimate accommodative amplitudes in the adults by +0.19D but in the younger age-group AoA was underestimated by −0.14D. Similar to the current study, Taub et al. recorded no significant difference between the push-up and Hofstetter's expected average data. In the present study, the push-up method was more accurate for the 10–19 age-group with a minimal overestimation of accommodative amplitude by +0.01D (in relation to Hofstetter's formula) but the overestimations became greater as the age increased. The implication is that even within the same population certain methods are more suitable than others for measuring AoA in different age-groups. The present study therefore supports the recommendation of age-appropriate methods for measuring AoA in clinical settings and perhaps for different populations as well.

The minus lens, push-down, and modified dynamic retinoscopy (by comparing means of measured values) failed to predict accurately age-expected norms using Hofstetter's

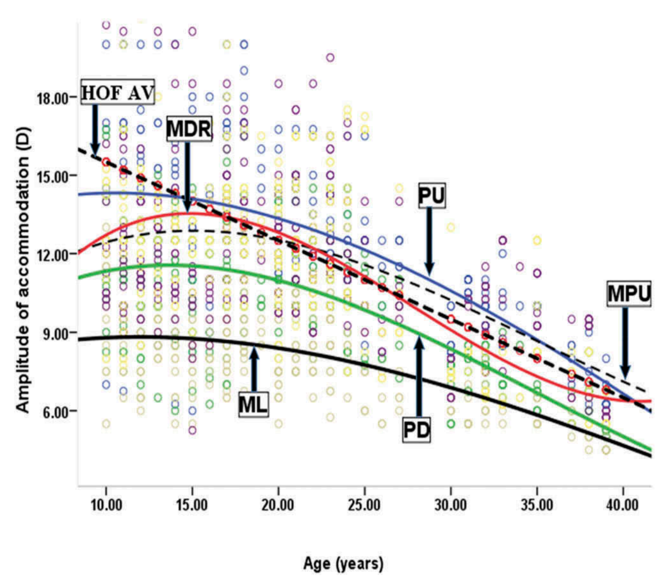

Figure 1. A scatter plot of AoA as a function of age using a polynomial fit. PU: push-up, PD: push-down, ML: minus lens, MDR: modified dynamic retinoscopy, MPU: modified push-up, HOF AV: Hofstetter's average.

formula in this study population. However, the objective method (modified dynamic retinoscopy) recorded the strongest agreement between all the measured amplitudes and Hofstetter's average (ICC = 0.78, $p < 0.001$), and also showed a strong agreement with the push-up method (ICC = 0.71, $p < 0.001$). For the fact that this is an objective method which does not rely on the patient's responses, this study recommends its use among this population. The push-up and push-down methods which overestimated and underestimated accommodative amplitudes by +0.42D, and −0.48D, respectively, also recorded a strong agreement levels between each other (ICC = 0.70, $p < 0.001$). This finding is consistent with the results of Momeni-Moghaddam et al.[14] and Woehrle et al.[21] These results support the clinical use of either of the two techniques. It also supports the recommendation by some authors that averaging the push-up and push-down results could correct for measurement errors and thus offset their over- and underestimations.[2,14] The current finding is, however, contrary to the results of Antona et al.,[19] who found a poor agreement between the push-up and push-down methods. In the present study, the push-up (+0.42D) and the modified push-up (−0.43D), respectively, recorded the least over- and underestimated accommodative values (in relation to Hofstetter's formula); these same methods were comparable to Hofstetter's average values, indicating their suitability for measuring AoA in this population. Perhaps, averaging the push-up and modified push-up results would be an alternative of obtaining accurate AoA results in our population. A limitation of this study is that we performed non-cycloplegic refraction and therefore some latent hyperopes may have been included. The inclusion of latent hyperopes would mean that accommodative amplitudes could have been underestimated for those participants. Another limitation of the study was the wider age bins of the age categorization. Our age categorization as in previous studies was not based on any standardized criterion. The use of smaller age-group bins, however, would have further confined the age-appropriate techniques to a rather smaller age-group, making it more specific. We recommend that future studies of this nature should consider smaller age-group bins.

Conclusion

Both the push-up and modified push-up methods were similar to Hofstetter's normative data, suggesting the suitability of these methods for the measurement of AoA in Ghanaian older children and adult non-presbyopes. As age decreased, the push-up results compared closest with Hofstetter's normative values and became more accurate for the younger age-group 10–19 years. On the other hand, the modified push-up method was more suitable with increasing age and became the most accurate for measuring AoA for the older age-group 20–39 years. The study also supports the use of the modified dynamic retinoscopy as an objective method of measuring AoA in Ghanaian non-presbyopes.

Conflict of interest

The authors report no conflicts of interest.

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