Original Article

Accommodative amplitude using the minus lens at different near distances

Hamed Momeni-Moghaddam[1,2], Jason S Ng[3], Bruno Mario Cesana[4], Abbas Ali Yekta[2,5], Mohammad Reza Sedaghat[6]

Purpose: The purpose of this study was to compare the mean findings and the repeatability of the minus lens (ML) amplitude of accommodation (AA) at 33 cm and 40 cm. **Materials and Methods:** AA was measured from the dominant eye of 120 fully corrected subjects using the ML procedure when viewing the target at both 33 and 40 cm. Each measurement was repeated between 24 and 48 hours after the first trial. **Results:** Mean AA when tested at 33 cm and 40 cm was 10.20 diopter (D) (standard deviation [SD] =1.24) and 8.85 D (SD = 1.23), respectively (P < 0.001). The limits of agreement of the measured amplitude calculated with taking into account of the replicates at 33 and 40 cm were − 0.19 (95% confidence interval [CI]: −0.34 to −0.04) and 2.53 (95% CI: 2.38 to 2.68), respectively. The repeatability of testing at the two distances 33 and 40 cm was ± 1.24 and ± 0.99, respectively. In addition, the retest reliability of measured amplitude using the intraclass correlation coefficient was 0.87 (95% CI: 0.789–0.920) at 33 cm and 0.91 (95% CI: 0.872–0.945) at 40 cm. **Conclusion:** There is no agreement in the obtained amplitude at the two measurement distances. Testing the ML AA at 40 cm may be superior given that a lower repeatability coefficient was observed. However, it is unclear whether the larger amplitude measured at 33 cm reflects a larger increase in accommodation (greater proximity effect) or a decrease in the ability to perceive the first slight sustained blur.

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Accommodation refers to a temporary change in the refractive power of the crystalline lens resulting from contraction of the ciliary muscle, thereby altering the location of the point in space optically conjugate with the retina.[1] Clinical measurement of the amplitude of accommodation (AA) provides an indication of the maximum accommodative ability. A reduced amplitude may reflect functional difficulties resulting from a failure to initiate or maintain an appropriate accommodative response, uncorrected refractive error (particularly latent hyperopia), or a wide range of systemic conditions.[2]

In the clinical setting, the AA is most commonly measured subjectively, using either the push-up (PU) or minus lens (ML) technique.[1] The stimulus to accommodation is increased either by advancing the target (PU) or by keeping the target stationary while adding ML power over the refractive correction (ML). The PU procedure may overestimate the finding due to the increase in the angular subtense of the stimulus as it approaches the patient and also because accommodative response changes have been shown to be less with changes in lens power than with changes in viewing distance.[1,3] Subjects are more sensitive at detecting the presence of blur with a smaller target, and so the perceived magnification resulting from the approaching target results in a delay in the first report of slight sustained blur and accordingly a higher subjective AA.[4,5] Indeed, several studies have observed a higher mean AA value with the PU technique, when compared with the ML procedure.[4,6,7]

While it is most commonly recommended that the ML procedure be performed at a viewing distance of 40 cm, corresponding to an initial accommodative stimulus of 2.50 diopter (D), the effect of changing the viewing distance on this standard clinical procedure has not been examined. Given that the goal is to measure maximum accommodation, it is important to know whether changing the target distance will result in a significant difference in the ML finding. Previously, in a study that compared the ML procedure performed at 6 m and 40 cm, the latter test distance was found to result in a higher AA.[8] As most clinicians perform measurements of AA at near distances, the aim of the present study was to compare the AA measured using the ML technique using target distances of 33 and 40 cm and to measure the repeatability of this parameter at these two distances.

Materials and Methods

The study was performed on 120 students (50 males and 70 females). Their mean age was 21.20 years (standard

[1]Health Promotion Research Center, Zahedan University of Medical Sciences, Zahedan, [2]Department of Optometry, School of Paramedical Sciences, Mashhad University of Medical Sciences, [5]Refractive Errors Research Center, School of Paramedical Sciences, Mashhad University of Medical Sciences, [6]Eye Research Center, Mashhad University of Medical Sciences, Mashhad, Iran, [3]Southern California College of Optometry, Marshall B. Ketchum University, Fullerton, California, USA, [4]Department of Molecular and Translational Medicine, Biostatistics and Biomathematics Unit, University of Brescia, Brescia, Italy

Correspondence to: Mr. Hamed Momeni-Moghaddam, Department of Optometry, Parastar 2 Street, Ahmadabad Avenue, Mashhad, Iran. E-mail: hmomeni_opt@yahoo.com

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deviation [SD] = 1.46; range 18–24 years of age). The study followed the tenets of the Declaration of Helsinki and informed consent was obtained from all subjects after an explanation of the nature and possible consequences of the study. All subjects had best-corrected visual acuity of at least 6/6 in each eye at both 6 m and 40 cm.

Subjects were excluded from the study if they demonstrated any of the following: (i) strabismus at 6 m or 40 cm (as assessed by the cover test); (ii) PU accommodative amplitude below the normal range as quantified by Hofstetter's equations;[9] (iii) lag of accommodation (assessed using monocular estimate method retinoscopy at 40 cm)[10] outside the range of +0.25 to +0.75 D; (iv) monocular accommodative facility <10 cycles/min using ±2.00 D flippers; (v) mean spherical equivalent refractive error outside ±3.00 D or astigmatism >1.75 D; (vi) any history of ocular trauma, ocular disease, refractive surgery, or aphakia. Refractive errors were determined by static retinoscopy and refined by subjective refraction.

AA was measured using the ML technique at distances of 40 and 33 cm. A 30-min interval was allowed between the two sets of measurements. The order of testing, i.e. whether the 33 or 40 cm distance was tested first, was alternated across subjects. All testing was performed on the subject's dominant eye (as determined by the hole in the card test)[11] while the nondominant eye was occluded. For testing at 40 cm, subjects viewed the middle letter within a row of "20/30" letters (corresponding to a visual acuity of 40/60 or a decimal equivalent of 0.67). Using lenses mounted in a trial frame, ML power was added in 0.25 D steps on top of the subjective refractive correction until the letter first became "slightly blurry" and could not be cleared by the subject. Subjects were allowed up to 5–10 s for each lens presentation to clear the letters. At the first noticeable blur point, the subjects were asked to try with maximal accommodation expended and clear the print to sure reaching to the end point. The near acuity chart was positioned on a reading stand perpendicular to the line of sight of the subject with a luminance of approximately 50 cd/m^2.

The same procedure was used for testing at 33 cm, except a row of "20/25" letters was used (corresponding to a visual acuity of 33/50 or a decimal equivalent of 0.67). Thus, the target selected subtended an angle of 7.5 min of arc at both 33 and 40 cm, respectively. The AA was calculated as the amount of ML power added before the subject reported the first slight sustained blur, plus the dioptric value of the test distance (2.50 D or 3.00 D). To determine the repeatability of the procedure, these measurements were repeated for both target distances after a time interval of at least 24 h but not more than 48 h after the first measurement.

For PU amplitudes, the same "20/30" row of letters was placed at a distance of about 75 cm and was moved slowly toward subject. Subjects were requested to keep the target as clear as possible to get to the point of first sustained blur. The distance between target and the spectacle plane was measured with a millimeter ruler and converted to diopters. The acquired value was recorded as AA.

Data were analyzed by SPSS.17 software (SPSS for Windows, SPSS Inc. Chicago, IL, USA). The Bland–Altman method[12] was used to assess the agreement between the viewing distances taking into account of the replicates. The limits of agreement were determined as the mean difference ±1.96 times the SD of the differences (SD), calculated by means of a mixed model with the interactions between subjects and distance and between subjects and replicates as random factors, owing to the fact that the replicates are nonexchangeable within each method; in the above mixed model, have been included subject and distance as factor with distance as a fixed factor. Furthermore, the 95% confidence intervals of the upper and lower limits of agreement were calculated as the limits of agreement ± 1.96 × the standard error. For this purpose, the standard error of these limits was calculated from the formula $\sqrt{3SD^2/n}$, where n is the sample size and SD is the standard deviation of the differences.[13]

The presence of a proportional error has been assessed by testing the Pearson's correlation coefficient between the differences on the first replicates of the two distances and their mean; in addition, the same analysis has been carried out on the last replicates and on the difference between the means of the replicates and their mean.

Intraclass correlation coefficients together with their 95% confidence intervals (CIs) have been calculated for the two measurements (first and second) at each distance to evaluate the repeatability for each method that, in addition, has been quantified by the usual formula of $2\times\sqrt{2SD^2}$ where SD^2 is the sum of the variance of the replicates at each distance and of the interaction subject by replicates.[14] The significance level was considered as $P < 0.05$ in all tests.

Results

The mean spherical equivalent refractive error for the dominant eye was −1.56 D (SD = 1.12; range = Plano to −3.00). The mean (SD) for the PU technique was 10.70 D (1.01) in all subjects and separately in females and males were 10.80 D (1.04) and 10.56 D (0.96), respectively ($P = 0.21$).

Mean values of AA measured using the ML technique, the limits of agreement, and the confidence limits at the two working distances are presented in Table 1.

The agreement band is 2.72 (from 2.72 to − 0.19) that is about the 29% of the mean of the two replicates at the two considered distances and consequently, it has to be considered too wide for claiming between the agreement of the measurement at 33 and 40 cm. In addition, the presence of a proportional measurement error turned out to be not statistically significant ($P = 0.5093$ first measurement, $P = 0.2994$, second measurement, and $P = 0.9735$, mean of the measurements).

The AA measured with the target at 33 cm was significantly ($P < 0.001$) higher than that measured with the target at 40 cm, by on average 1.17 D [Fig. 1].

The mean and SD of accommodative amplitude measured by the PU method were 10.70 ± 1.01 D (95% CI: 10.51–10.88). The mean difference of the PU amplitude with the ML amplitude measured at 33 cm and 40 cm was 0.67 ± 1.55 D (95% CI: 0.39–0.95) and 1.84 ± 1.51 D (95% CI: 1.50–2.11), respectively.

Table 2 shows mean, SD, mean difference, and the repeatability of the repeated measurements of accommodative amplitudes at the two distances.

The mean differences between the two trials were different for the two viewing distances (0.24 D for distance 33 cm and 0.16 D for 40 cm) and the coefficient of repeatability (COR) was higher for the 33 cm (±1.24 D) when compared with the 40 cm test distance (±0.99 D).

A significant correlation was observed between the first and second readings at both distances 33 cm ($r = 0.77$; $P < 0.001$) and 40 cm ($r = 0.86$; $P < 0.001$) as expected.

Discussion

The results of the present study demonstrated a significantly higher mean ML AA when tested at 33 cm, compared with the value obtained at 40 cm (mean difference = 1.17 D). It seems likely that a large proportion of this difference is due to a greater proximally induced accommodative response at the closer viewing distance (note: the term proximally induced accommodation is chosen since this is likely to include both proximal accommodation and proximal vergence driving convergence accommodation).[15,16] In addition, the repeatability of the measurements was superior at the farther distance, with a COR of ± 1.24 D and ± 0.99 D being recorded at 33 and 40 cm, respectively.

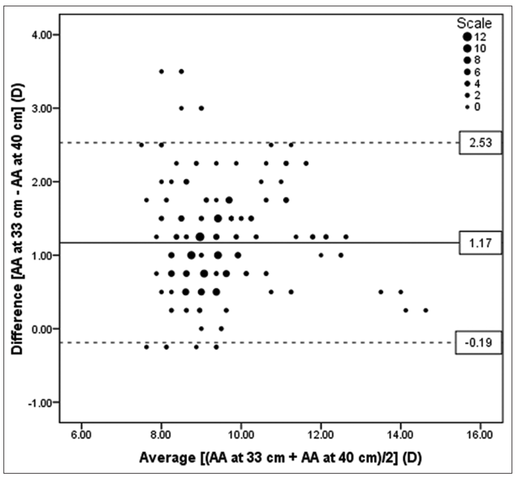

Figure 1: Bland–Altman plot showing the difference between the measurements of amplitude of accommodation at the two test distances as a function of the mean finding (n = 240, two measurements for each subjects). The mean difference is shown by the solid horizontal line, while the 95% limits of agreement are indicated by the dashed horizontal lines

The mean AA results found in this study were similar to previous studies using the ML procedure at 40 cm[8,17,18] and at 33 cm,[19] while the CORs determined in this study at either distance were generally smaller compared to previous reports.

If the goal of the AA procedure is to achieve maximum accommodation, then using a closer viewing distance is preferable. Given that greater proximally induced accommodation will become manifest at even shorter distances, one might speculate that even closer viewing distances are preferable. However, the perceived size of the target must also be taken into account. When working at more proximal distances, the target will subtend a larger angle at the eye, and given the reduced blur sensitivity with larger targets,[4,5] an increased AA may simply reflect the failure of the subject to perceive target blur resulting in a delayed endpoint rather than increased accommodation.

An additional factor to consider is the effect of pupillary constriction on the depth of field. It is well established that the pupil diameter decreases concurrent with an increase in accommodation.[20] However, Phillips *et al*.[21] showed minimal change in pupil size when accommodation was stimulated with blur-driven accommodation alone. They suggested that cues such as target size and/or proximity may be a more significant stimulus. Accordingly, one might speculate that testing at a closer viewing distance may result in a smaller pupil diameter (and therefore larger depth of focus) when compared with a longer distance. Such an increase in depth of focus would delay the perception of blur, thereby resulting in a higher measurement of AA.

Table 1: Mean values of the accommodative amplitude using minus lens method (D), the limits of agreement and confidence limits at the two working distances tested (*N*=240)

Distance	Mean±SD (95% CI)	Range (Min., Max.)	Mean difference 33-40 cm (95% CI)	Limits of agreement	
				Lower (95% CI)	Upper (95% CI)
33 cm	10.02 ± 1.24 (9.87-10.18)	7.25 (7.50, 14.75)	1.17±0.68 (1.08-1.25)	-0.19 (-0.34 to 0.04)	2.53 (2.68 to 2.38)
40 cm	8.85 ± 1.23 (8.70-9.01)	8.25 (6.25, 14.50)			

Table 2: Repeatability between the repeated measurements of the amplitude of accommodation with the Minus lens method at 40 and 33 cm (*N*=120)

Distance trial	33 cm		40 cm	
	Mean±SD (95% CI)	Range (Min., Max.)	Mean±SD (95% CI)	Range (Min., Max.)
First	9.90 ± 1.25 (9.67-10.13)	7.25 (7.50, 14.75)	8.77 ± 1.29 (8.54-9.01)	8.25 (6.25, 14.50)
Second	10.15 ± 1.22 (9.93-10.37)	6.00 (8.25, 14.25)	8.93 ± 1.16 (8.72-9.14)	7.50 (6.25, 13.75)
Mean difference (second – first) (95% CI)	0.24 ± 0.58 (0.14-0.35)		0.16 ± 0.47 (0.07-0.24)	
ICC (95% CI)	0.87 (0.789-0.920)		0.91 (0.872-0.945)	
Repeatability coefficient	±1.24		±0.99	

It should also be noted that all subjective methods for assessing the AA overestimate the maximum accommodation as a result of the depth of focus of the eye, when compared with objective techniques that measure the actual change in response, such as the use of an autorefractor or dynamic retinoscopy.[19] In confirming this results, Anderson and Stuebing investigated the differences between objective measures of AA as compared to subjective AA measures (PU or MLs) and mentioned that the objective measured amplitude is substantially less than the subjective PU technique.[22] Wold *et al*.[23] suggested that while subjective measurements of the AA are not adequate for assessing the change in the optical power of the eye, they may provide a useful assessment of near reading ability. For example, a common clinical procedure to determine a near addition lens is to calculate the difference between the required stimulus (in diopters) and 50% of the subjective amplitude.[1]

It is also worth considering why 40 cm (16 inches) has been widely chosen as the standard near test distance and whether this is still appropriate given modern near-vision demands. While this value is often quoted as a typical near viewing distance for adults, Wittenberg and Grolman[24] examined the accommodative demand for a range of 23 occupations and reported mean values ranging from 1.50 to 4.63 D, with an overall range between 1.38 and 6.50 D (equivalent to viewing distances between 15 and 72 cm). Further, an examination of children between 6.4 and 10.75 years of age found mean habitual reading and writing distances of 27.2 and 27.7 cm, respectively.[25] In addition, the use of modern technology such as smartphones has also changed viewing conditions. A recent study showed that the mean viewing distance when reading an internet web page on a smartphone was 32.2 cm, with a range from 19.0 to 60.0 cm.[26] Accordingly, the use of 40 cm as a near test distance for all subjects may no longer be appropriate that is in contrast with the current study which indicate better repeatability of the measurements at 40 cm. This can possibly attribute to the lesser load on the accommodative system.

Conclusion

These results indicate that although testing the ML AA at 33 cm produces a higher response, greater test repeatability was observed with testing at 40 cm. However, it is unclear whether the larger amplitude reflects a larger increase in accommodation or a decrease in the ability to perceive the first slight sustained blur. Further studies to evaluate the optimal distance for performing this standard clinical procedure would be valuable. Hence, it will be a good idea to include various distances, and this way to evaluate the effect of different parameters, such as blur sensitivity and proximal accommodation, to determine that which factor (s) has (have) the most effect on the measurement of the AA with this method.

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Conflicts of interest

There are no conflicts of interest.

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