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OPTOMETRY AND VISION SCIENCE

ORIGINAL ARTICLE

Evaluation of Infant Accommodation Using Retinoscopy and Photoretinoscopy

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ABSTRACT

Purpose. To compare PlusOptix PowerRefractor (PR) and Monocular Estimation Method (MEM) for measurement of infant accommodation and to assess the usefulness of applying individual calibration factors to PR data.

Methods. Subjects were 41 infants aged 3 to 12 months. Accommodative response was measured by MEM and PR at 33 and 57 cm, acuity by Teller Acuity Cards, and cycloplegic refractive error (RE) (tropicamide 1%) by retinoscopy (Wet Ret) and PR (PR C). Monocular wear of a +2.00 diopter (D) and +4.00 D lens established a PR calibration factor for each subject.

Results. The median individual calibration slope was significantly different from 1.0 (+0.91; Wilcoxon signed-rank test: $p = 0.03$), yet there was no correlation between individual calibration slopes and the difference in RE by Wet Ret and PR C ($r_s = 0.05$, $p = 0.76$). For 19 infants with an accommodative response slope by PR of >0.50, the mean lag was not significantly different between methods (0.50 D PR, 0.48 D MEM; $p = 0.92$; 95% LoA = ±1.78 D). Despite the improvement in acuity with age ($r_p = -0.56$, $p < 0.0001$), neither age nor acuity had a significant effect on accommodative error. Lag was greater at 57 cm (0.69 D) than 33 cm (0.30 D, $F_{1,18} = 6.3$, $p = 0.022$), but lag was unrelated to RE ($F_{1,17} = 3.3$, $p = 0.09$). Accommodative response slopes for boys were larger (1.5) than for girls (1.0; $F_{1,17} = 9.5$, $p = 0.007$).

Conclusion. MEM and PR provided similar estimates of RE and of accommodative lag once the PR data were screened for inattention using an accommodative response slope criterion. Adult-like accommodative responses between 3 and 12 months of age suggest that acuity at these ages is not limited by accommodative immaturity. Further, mature accommodation may attenuate RE-related defocus signals for emmetropization.
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Key Words: infant, accommodation, photorefraction, hyperopia, acuity, gender, development

Assessment of the accuracy of the accommodative response may become an increasingly important part of the examination of infants. Hyperopic defocus from accommodative errors at distance, and particularly at the near distances that predominate in infancy, is reported to be a signal for emmetropization.[1,2] Experimental models using animals suggest that the coordinated growth of ocular components, with a goal of an ideal refractive state, is regulated by defocus on the retina.[3–5] Emmetropization is effective in decreasing the initial levels of hyperopia in the majority of infants. The average cycloplegic spherical equivalent (SEQ) refractive error (RE) of human infants has been found to be about +2.00 diopter (D) at 3 months, decreasing to +1.00 to +1.50 D at 12 months of age with significant decreases in hyperopia and its standard deviation with age during emmetropization.[6,7] It has been suggested that the operating range for human emmetropization extends from approximately +1 D to +5 D of hyperopia at 3 months of age.[7] Failure to emmetropize affects approximately 7 to 9% of the most highly hyperopic infants at the upper limits of this range.[8,9] Measurement of the accuracy of accommodation in these highly hyperopic infants may provide information about the magnitude of defocus cues available to the infant and the likelihood for eventual emmetropization.

It has also been suggested that the amount of accommodative lag may have diagnostic value in an older hyperopic infant or child once the period for emmetropization is past.[10] Rather than depending on the absolute level of cycloplegic RE, widely ranging clinical guidelines,[11,12] or unreliable subjective symptoms when deciding whether to prescribe a refractive correction, the clinician might use objectively measured accommodative lag as an indication of whether the underlying hyperopia warrants correction.

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Accommodative error can be measured using several methods, including Monocular Estimation Method (MEM), Nott retinoscopy, and photoretinoscopy. Photoretinoscopy is often used to measure distance RE,[13] but can also be used to measure accommodative response or error. The PowerRefractor (PR) (PlusOptix, Germany, www.plusoptix.de) is a commercially available photorefractor. The working range of REs for which the PR can accurately record is about +4.00 D to −6.00 D with respect to infinity.[14–17] Although techniques for measuring accommodative error have been compared in young adult subjects,[18,19] infants' accommodative error has only been studied by either dynamic retinoscopy[20–23] or photorefraction.[13,23,24] A recent study of the validity of measurement of non-cycloplegic RE in infants using the PR found the technique to be valid, but suggested that individual calibration may be necessary to obtain accurate readings. They hypothesized that the readings might be influenced by optical characteristics of the eye, such as retinal reflectance, requiring correction by individual calibration for each subject.[25]

The PR might be preferred in a screening setting over MEM because of the lower cost associated with not having to use professionally qualified examiners. Clinicians might consider using the PR rather than MEM because of the ability to examine the two eyes at once without the use of trial lenses at a close distance or the bright light of the retinoscope, thereby improving efficiency and comfort. The previous version of photorefractor, marketed by Multichannel systems, has been used effectively in the laboratory to study the accommodation of human infants. However, the subject is examined using a beam splitter system to keep the PR, infant, and the fixation target coaxial. The data are scrubbed to eliminate fixations beyond 15°, sections where data are missing, infants who do not respond to changes in target distance, and accommodative data where lag exceeds 1D.[26] The currently available PlusOptix version of the PR does not allow for all data to be extracted for scrubbing. Although the requirement that babies accommodate within 1D of the target vergence allows for important analyses of accommodation to be performed, it may be of interest to determine the range of accommodative responses displayed by infants without imposed, strict limits. Additionally, the laboratory beam splitter arrangement may not be suited for general clinical use. The purpose of the current study was to evaluate the performance of the PlusOptix PR for the measurement of infant accommodation in a general clinical setting against an accepted "gold standard" retinoscopic technique, MEM. The effect of individual calibration using slope, or slope and intercept, calculated from regression data after application of monocular trial lenses was also assessed. Age, acuity [Teller Acuity Cards, (TAC)], and cycloplegic RE were also analyzed for their role as covariates that might affect accommodation or instrument performance.

METHODS

Forty-one infants aged 94 to 366 days were seen for this cross-sectional study between January 2005 and January 2006. The mean age of the 41 infants in the study was 7.68 ± 3.08 months with each month of age represented by at least two infants, except for 8 to 9 months (Fig. 1). This research followed the tenets of the Declaration of Helsinki, was approved by the institutional review board at The Ohio State University, and informed consent was

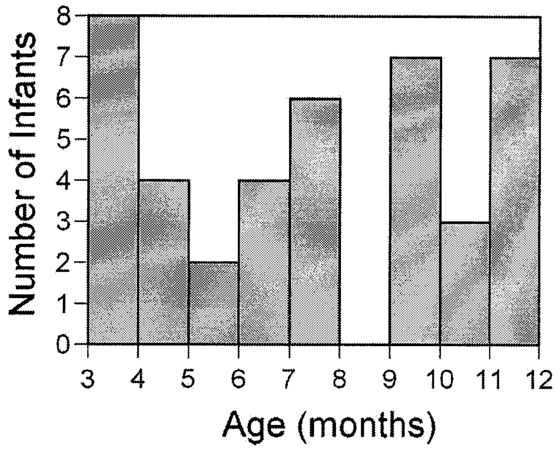

FIGURE 1.
Number of infants in each age group in months (days/31).

obtained from the parent or guardian of the subject after explanation of the nature and possible consequences of the study. To be included in the study, the infant must have been between 3- and 12-months-old with a birth weight of at least 5.5 pounds (2500 grams), no history of ocular disease or active ocular inflammation, no strabismus or history of sensitivity to anesthetics or preservatives in eye drops, no cardiac, liver, or respiratory abnormalities, and must have been under the care of a pediatrician.

Acuity Measurement

After informed consent, the infant's binocular visual acuity was determined using preferential looking and TAC. The subject was seated on a parent's lap, 55 cm from the cards and a stage. The parents were instructed not to move or give the infant any other cues about the location of the stripes. The examiner began by holding up the 0.31 cycles/degree stripes. The examiner judged the location of the child's fixation by viewing through a peephole in the middle of the card. Successively smaller patterns were presented until the subject no longer displayed preferential looking to the correct side of the card. When a correct look was no longer noted, that card was presented one more time. If the infant again showed no preference or a preference to the incorrect side, no more cards were shown. If a correct response was then noted two times, a card with smaller stripes was then presented. Final results were recorded as the cycles/degree of the last card with which a response was noted. Acuity scores converted to logMAR values for analysis.

MEM Accommodation Measurement

Accommodative error was then tested using MEM and PR at 33 and 57 cm (MEM 33; MEM 57; PR 33; PR 57). During both techniques the room illumination was 30 lux and kept constant for each subject, who was seated on the parent's lap facing the examiner. During MEM, a 9 × 9 cm two-dimensional detailed picture of a cartoon mouse, as seen in Fig. 2, was attached to a Keeler streak retinoscope. The size of the mouse target also allowed the infant to view part of the examiner's face. The horizontal meridian of the right eye was neutralized only when the infant was attentive. Attention was assumed when fixation, facial recognition, and pupil

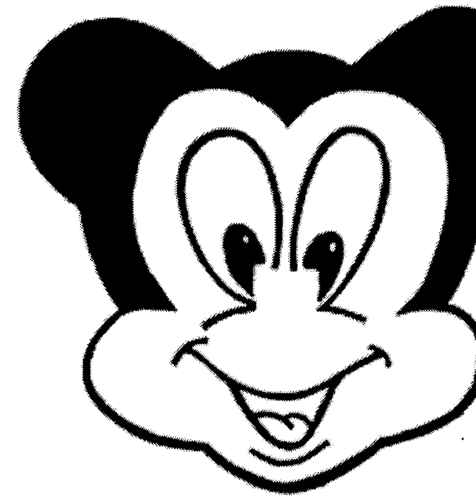

FIGURE 2.
Cartoon mouse target attached to the retinoscope during MEM (not actual size).

constriction occurred. During an alert period, a lens from a lens bar was inserted briefly in front of the infant's right eye. The lenses were arranged in intervals of 0.50 D, and the range of lenses that allowed for neutrality of the retinoscopic reflex was recorded. This technique was first performed 33 cm from the subject, then with the same mouse target at 57 cm. The order of PR and MEM was randomized, but within each technique the 33 cm measurement was done before the 57 cm measurement.

PowerRefractor Accommodation Measurement

During the binocular PR accommodative error measurement, the camera was placed at a constant distance of 1 meter from the infant's eyes. Before the measurements began, the degree of fixation error around the camera during which the PR would take measurements was changed to 30° from the default setting of 20°. This was done to allow for measurements to occur with the subject in up-gaze as he or she looked at the target. The targets used during PR measurements were multicolored plush toys held 33 cm (mouse) then 57 cm (firefly) from the infant's eyes and just above the axis of the camera. These toys were selected for having broad-band spatial frequency content similar to those used in other infant accommodation work.[26] The PR measurements taken 33 and 57 cm from the infant were converted to accommodative error first by finding the error in the horizontal meridian, then by adjustment for the dioptric demand at 33 cm and 57 cm with the following formulas:

$$\text{PR 33 accommodative error (D)} = 3 + \text{PR 33 (horizontal)}$$

$$\text{PR 57 accommodative error (D)} = 1.754 + \text{PR 57 (horizontal)}$$

It should be noted that because infant RE was not corrected during measurement, accommodative demand was not a constant for all infants.

TABLE 1.
Example calibration data

Monocular trial lens power	Anisometropia with each trial lens	Data used in calibration regression
Plano	−0.375	0.00
+2.00 D	1.875	2.25
+4.00 D	3.00	3.375

The initial anisometropia with no lens in place was subtracted from each of the three levels of anisometropia to yield the data used in the calibration regression (y axis) against 0.00, 2.00, and 4.00 (x axis). The calibration equation for this subject was $y = 0.84x + 0.19$.

PR Individual Calibration with Monocular Trial Lenses

Calibration information for the PR was obtained following the accommodative measurements. A +2.00 D loose lens was held in the right hand of the parent and was placed in front of the subject's right eye. It was held as close to the infant's right eye as possible without contact with the subject's face during the measurement. Another plush toy (chicken) was held just above the camera. A similar measurement was then taken with a +4.00 D lens and again with no lens. Individual calibration slopes were determined for each subject. The difference between the SEQ found in each eye using non-cycloplegic PR readings (PR 1 m) with no lens in place was subtracted from the difference between the SEQ found in each eye with a +2.00 D and a +4.00 D lens in front of the right eye. The change in anisometropia represented the effect of the monocular +2.00 D or +4.00 D lens. The calibration slope for each subject was calculated by linear regression using three points: the initial anisometropia with no trial lenses set to zero, and the increase in anisometropia relative to when no lens was in place as a function of +2.00 D, and +4.00 D trial lenses. An example is shown in Table 1.

Cycloplegic RE

One drop of 0.5% proparacaine was put in each of the subject's eyes followed immediately by 2 drops of 1% tropicamide instilled 5 minutes apart. Thirty minutes after the installation of the last drop, retinoscopy and PR were conducted in random order to measure cycloplegic RE in both eyes. During the retinoscopic measurement, the examiner found neutrality in two meridians using lens bars containing lenses at 0.50 D intervals. During each PR measurement for accommodative error, RE, and for calibration, the "Full refraction mode" was used and the target was wiggled to keep the subject's attention. If needed, the examiner placed her head next to the toy to keep the infant interested at that distance until the PR stopped automatically with the "Autoshot" mode. This mode was chosen because the manufacturer's software modification for extracting data from the "Dynamic-mode" was not available to the investigators at the time of the study or to clinicians purchasing the unit. Once supplied, the software did not deliver continuous data; there were substantial random gaps in the recordings.[27] These "Autoshot" data are intended to parallel what might be obtained in clinical use of the commercially available instru-

TABLE 2.
Mean and SD for PR C reading , and Wet Ret for the values of SEQ, J_0, and J_{45} in each eye

	Mean (D)	SD
PR C OD SEQ	+2.11	1.25
PR C OD J_0	+0.02	0.31
PR C OD J_{45}	+0.08	0.22
PR C OS SEQ	+2.59	1.36
PR C OS J_0	+0.02	0.41
PR C OS J_{45}	+0.02	0.20
Wet Ret OD SEQ	+1.80	1.29
Wet Ret OD J_0	+0.17	0.42
Wet Ret OD J_{45}	0.00	0.00
Wet Ret OS SEQ	+2.07	1.29
Wet Ret OS J_0	+0.17	0.39
Wet Ret OS J_{45}	0.00	0.00

ment. During all PR measurements, the results of the PR were covered and masked from the examiner's view. If the measurements did not automatically stop after about 30 s, the examiner re-positioned the toy to allow the measurements to resume. For simplicity, only data from the right eye were used in PR accommodation analyses.

Statistical Methods

p values reported are from paired Student's t-test unless noted otherwise. Correlation coefficients are Pearson when designated r_p (equal variance assumptions met) and Spearman when designated r_s (equal variance assumptions not met). F-statistics are from repeated measures ANOVAs performed with test method and test distance as repeated factors, age, acuity, gender, and RE as between-subject factors. Statistical analyses were carried out using SPSS (v.15.0; SPSS, Chicago).

RESULTS
Calibration

Refractive error obtained with cycloplegic PR and cycloplegic retinoscopy (Wet Ret) is summarized in Table 2. The following analyses comparing distance RE by Wet Ret and PR C exclude one outlying subject with a 3.50 D discrepancy between the two techniques. The SEQ for PR C was significantly more hyperopic compared with Wet Ret in each eye (OD mean difference = 0.40 ± 0.77 D, $p = 0.002$; OS mean difference = 0.62 ± 0.93 D, $p < 0.0001$). The horizontal/vertical component of astigmatism (J_0) was more positive by retinoscopy than by the PR in each eye (OD mean difference = −0.16 ± 0.30 D, $p = 0.001$; OS mean difference = −0.18 ± 0.41 D, $p = 0.011$). The oblique component of astigmatism (J_{45}) was statistically significantly more positive by retinoscopy than by the PR in the right eye only, but clinically negligible in amount (OD mean difference = 0.08 ± 0.23 D, $p = 0.027$). The comparability of Wet Ret and PR C data was also evaluated using orthogonal regression. The slope between PR C SEQ and Wet Ret SEQ was 1.05, which was not was significantly different from 1.0 (95% Confidence Interval = 0.82, 1.34, Fig. 3). This indicates that despite the small hyperopic bias in PR, each technique measured similar between-subject differences in RE. The width of the confidence interval for the slope indicates substantial individual variability. The 95% limits of agreement between PR C and Wet Ret were ±1.50 D [Fig. 4 (a)]. Differences between PR C and Wet Ret were not correlated with the mean RE [$r_s = -0.002$, $p = 0.99$ OD; $r_s = -0.018$, $p = 0.91$ OS; Fig. 4 (a)].

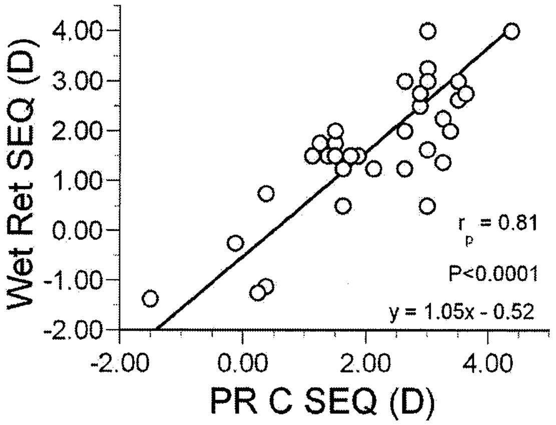

FIGURE 3.
Cycloplegic SEQ distance RE reading in the right eye (D) measured by PR C SEQ vs. retinoscopy (Wet Ret SEQ). The slope of 1.05 was not was significantly different from 1.0 but the 95% confidence interval was wide (95% CI = 0.82, 1.34), indicating good but variable agreement. One subject with a 3.50 D discrepancy between the two techniques has been removed.

If this variability between the two techniques were due to systematic errors, individual calibration should account in part for some of that variability. Individual calibration slopes were evaluated for their relationship with the individual differences between cycloplegic retinoscopy and PR measurements of distance RE. The median slope of calibration was +0.91 (25th percentile = 0.53, 75th percentile = 1.10), which is significantly different from 1.0 (Wilcoxon signed-rank test, $p = 0.03$). However, there was no correlation found between the difference in SEQ obtained by Wet Ret and PR C and the individual calibration slopes ($r_s = 0.05$, $p = 0.76$). Nine subjects had calibration slopes that were <0.50. The median calibration slope when these subjects were excluded was +1.02, which was not significantly different from 1.0 (Wilcoxon signed-rank test, $p = 0.94$). There was still no correlation found between the difference in SEQ obtained by Wet Ret and PR C and the individual calibration slopes using only these 32 subjects ($r_s = 0.095$, $p = 0.61$). Adjustment of individual PR C values using the subject's own calibration slope and intercept increased the 95% limits of agreement between PR C and Wet Ret in these 32 subjects (±1.46 D without adjustment and ±2.12 D with adjustment). Therefore, adjustment of RE measured with PR using individual calibration slope, or slope and intercept, calculated by regression using data from monocular trial lenses did not improve the agreement with retinoscopy. This suggests that the primary source of variability between the two techniques might be more random than systematic.

Accommodation

Considering the results above, accommodation data were analyzed without adjustment for the calibration results from trial

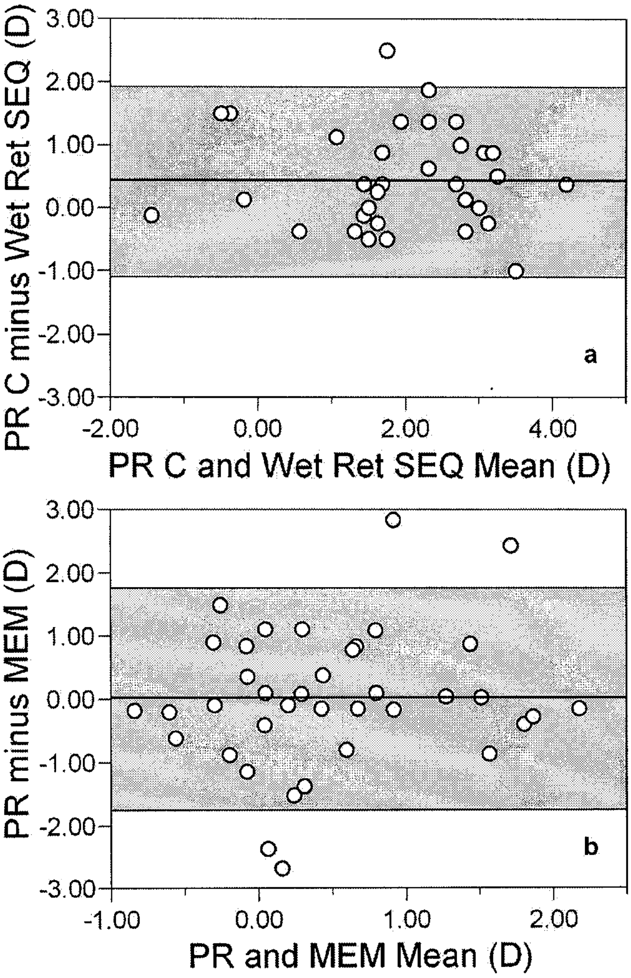

FIGURE 4.

(a) Difference (PR C minus Wet Ret) vs. mean plots for cycloplegic distance RE. (b) Difference (PR minus MEM) vs. mean plots for accommodative error. Data for 33 cm and for 57 cm are represented on the single plot. The shaded area represents the 95% limits of agreement. The horizontal line indicates the average difference between methods.

lenses. PR data were adjusted for all subjects, however, by subtracting the 0.40 D found in the right eye comparison with cycloplegic retinoscopy. Using data from all infants, each of the four techniques showed a significant non-zero net average lag of accommodation (MEM 33 +0.37 ± 1.05 D, $p = 0.03$; MEM 57 +0.69 ± 0.94 D, $p < 0.001$; PR 33 +1.30 ± 1.45 D, $p < 0.0001$; PR 57 +0.44 ± 1.05 D, $p = 0.011$). PR at 33 cm yielded a significantly larger lag than MEM at 33 cm (difference = +0.97 ± 1.57 D, $p < 0.0001$) and had the largest standard deviation of both distances and techniques (±1.45 D). However, PR at 57 cm was not significantly different from MEM at 57 cm (difference = −0.21 ± 1.23 D, $p = 0.28$).

The large accommodative error for PR at 33 cm suggested that lack of attention may have affected readings at this closer distance. This factor was evaluated in two ways. First we scored the fixation patterns, the marks recorded on the screen of the PR of where the infant was fixating during the measurement, and excluded data where the infant fixated beyond 30° more often than within 30° during the measurement, if the infant's fixation extended beyond more than two quadrants of the screen, if cylinder values were 1.0 D more than found during PR C, or if fixation was more often central rather than on the toy held next to the PR. Undesirable patterns of fixation occurred 32% of the time at 57 cm (13/41) and 71% of the time at 33 cm (29/41). Poor fixation at one distance was not associated with poor fixation at the other distance ($x^2_1 = 0.35$, $p = 0.55$). Elimination of data from infants displaying poor fixation did not significantly affect the higher lag found with PR at 33 cm. Infants with good fixation had lag values of 1.11 ± 1.61 D with PR at 33 cm and infants with poor fixation had lag values of 1.36 ± 1.41 D (independent sample t-test; $p = 0.64$). Because eliminating data from infants with poor fixation did not significantly decrease the lag found by the PR at 33 cm, evaluation of the fixation pattern may not be a reliable indicator of attention.

The second approach used a method suggested by Candy and Bharadwaj, which is based on the responsiveness of the infant to changes in target distance.[26] Infants were included in the analysis only if they displayed an accommodative response slope of ≥0.50. This criterion was met by 90% of infants during MEM 9(36/40) and by 46% of infants during PR (19/41, $x^2_1 = 17.7$, $p < 0.0001$). The two techniques provided similar assessments of accommodative response in this sub-sample of 19 infants. The average slopes of the accommodative response function were not significantly different (1.30 ± 0.54 for MEM and 1.23 ± 0.67 for PR; $p = 0.75$). Repeated measures ANOVA of accommodative error using these 19 subjects confirmed that the effect of instrument was not significant ($F_{1,\ 18} = 0.01$, $p = 0.92$). The estimated mean accommodative error was 0.50 D by PR and 0.48 D by MEM [95% limits of agreement between methods = ±1.78 D; Fig. 4 (b)].

Factors such as age, acuity, astigmatism, SEQ distance RE, test distance, and gender might affect estimates of accommodative error. The mean visual acuity expressed as logMAR in the sample of n = 41 was 0.88 ± 0.82 octaves, a value that improved significantly with age (−0.045 logMAR per month, $r_p = -0.56$, $p < 0.0001$; Fig. 5). The SEQ distance RE also decreased with age when measured with PR (−0.25 D per month, $r_p = -0.61$, $p < 0.0001$) but not with Wet Ret ($r_p = -0.28$, $p = 0.077$, Fig. 6).

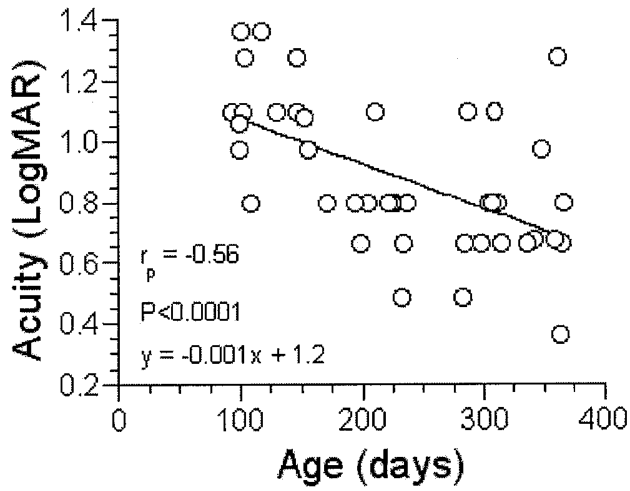

FIGURE 5.

Age (days) vs. Visual Acuity (logMAR). Also included is the Pearson correlation coefficient r_p and p-value.

The improvement in acuity was not due to changes in SEQ distance RE, however. When visual acuity was modeled as a function of age and SEQ distance RE, the only significant factor was age ($F_{1,39}$ = 17.5, p < 0.0001). Despite these improvements in acuity with age, neither age ($F_{1,17}$ = 0.87, p = 0.36) nor acuity ($F_{1,17}$ = 0.00, p = 0.98) had a significant effect on accommodative error in a repeated measured ANOVA using the sub-sample of 19 subjects. Astigmatism had no significant effect on the amount of accommodative error whether the astigmatism was measured using PR ($F_{1,17}$ = 1.34, p = 0.26) or Wet Ret ($F_{1,17}$ = 1.70, p = 0.21). There was also no significant effect of SEQ distance RE on accommodative error ($F_{1,17}$ = 3.3, p = 0.09).

Accommodative error did depend significantly on test distance and gender. Lag was greater at 57 cm (0.69 D) than at 33 cm (0.30 D, $F_{1,18}$ = 6.3, p = 0.022). This finding was consistent with the average accommodative response slopes exceeding 1.0. This finding was also consistent across methods as there was no significant method by distance interaction ($F_{1,18}$ = 0.003, p = 0.96). There was a significant interaction between gender and test distance ($F_{1,17}$ = 5.2, p = 0.036, Table 3). The highest amount of lag occurred in boys at 57 cm (Table 3). The average accommodative response function slope for boys (22/41 subjects) was therefore larger at 1.5 than for girls (19/41 subjects) at 1.0 ($F_{1,17}$ = 9.5, p = 0.007).

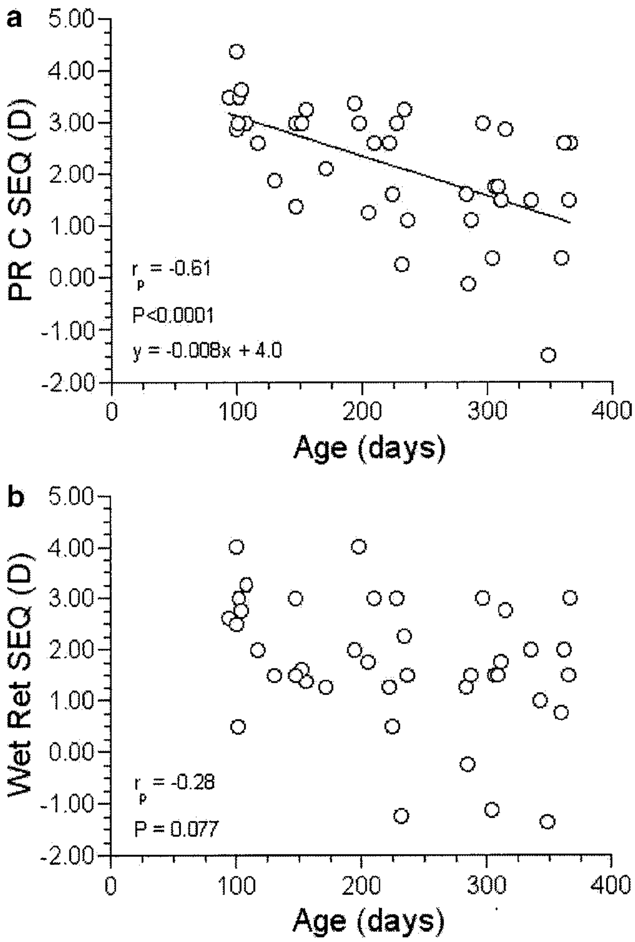

FIGURE 6.
Age (days) vs. cycloplegic SEQ RE reading in the right eye (D) measured by (a) PR C SEQ; (b) retinoscopy (Wet Ret SEQ). Also included are Pearson correlation coefficients r_p and p-values.

TABLE 3.
Estimates of the mean accommodative error by gender and test distance, adjusted for measurement method and distance refractive error

Gender	Test distance (cm)	Mean (D)	SD
Female	33	0.27	0.86
	57	0.33	0.91
Male	33	0.31	0.94
	57	1.01	0.83

DISCUSSION
Validity and Calibration

When data from all infants were analyzed, the accommodative error using PR at 33 cm (1.30 D) was substantially larger than at 57 cm and larger than lag measured using MEM at either distance. The different amounts of accommodative error found when using MEM and PR at 33 cm suggested that attention might be an important factor with PR. However, the MEM values in this study were very close to those found using Nott in previous infant studies by Banks and Brookman.[21,22] The range of neutral MEM values, high neutral vs. low neutral, was assessed within 0.50 steps, but no range was detected in any infant at either distance suggesting that infants were not using relative accommodation when lenses were introduced in front of the eye, a common criticism of MEM. The average slope of the accommodative response function with MEM was also closer to values seen in previous studies and similar to that from PR once data were limited to subjects who were responsive to changes in target distance.[13,20,21,23,24,28,29] MEM appears to be a valid technique to measure accommodative error in infants 3 to 12 months of age.

The PR appears to provide a valid measurement of RE, but with a small hyperopic bias. The SEQ distance RE found with PR C was between 0.40 and 0.62 D more hyperopic than that found with Wet Ret. The regression slope between the two methods measures of distance RE was not significantly different than 1.0. This agrees with several reports on the validity of PR measurements.[15–17,27,30] It has been suggested that calibration be done on individual subjects when measuring RE or accommodation with the PR, adjusting individual PR readings by a calibration equation obtained using trial lenses. The median infant calibration slope of 0.91 found in this study is similar to the mean adult slope reported in recent literature.[25] These individual calibration slopes were not related to the differences in SEQ found between PR C and Wet Ret. The absence of a relationship between calibration slope and error and the increase in the limits of agreement after using both calibration slope and intercept suggests that adjusting PR C by these calibration data would not bring PR C any closer to the Wet Ret value. Correcting PR readings to create agreement with Wet Ret seems to only require adjustment by a constant, on the order of 0.50 D found in this study. It is possible, however, that this offset between techniques may be different for each individual subject rather than a constant for all subjects. Evidence for the appropriateness of using an individual adjustment value would come from data not gathered in this current study showing that individual variations from the suggested group value of 0.50 D were repeatable. Some evidence for this possibility can be seen in the high degree of correlation between eyes for the difference between PR C and Wet Ret ($r_p = 0.69$, $p < 0.0001$). An additional limitation of these data is that most of the subjects in this study were of European ancestry. The effect of retinal pigmentation on PR readings also needs further detailed study.

Disagreement between the two methods' assessment of accommodation might be better explained by differences in attention rather than validity. Inattention was not reliably detected through analysis of the fixation patterns provided by the PlusOptix PR screen. Accommodative error was still not comparable between the two techniques when data were separated according to the examiners judgment of the quality of fixation. This could be due to an incorrect choice of criteria about the quality of fixation. Alternatively, the PR might be using data for its eventual report of RE that were different from the points that provided the screen pattern. Screening the data by performance seemed a more effective method.[26] Requiring that accommodative response slopes be ≥0.50 created agreement between the average values provided by the two methods with 95% limits of agreement between methods of ±1.78 D. Screening data by performance may still falsely eliminate some subjects who show poor accommodative performance for reasons other than poor attention. MEM does seem to command attention better than PR with 90% of MEM data being acceptable compared to only 46% of PR data. PR still has several potential advantages: measurement of the two eyes at once, no need for bright lights meaning better subject comfort, and the possible use of lay personnel as examiners. Consistent with a recent recommendation, it may be necessary to restrict the gaze allowance of the PR to 15° or less so that measurements will only be taken when the infant is looking in the direction of, and hopefully attending to, the target.[25] To fit the target within this range without blocking the camera, mirrors may be needed between the subject and the PR.

Covariates and Accommodative Error

There was no correlation between the amounts of accommodative error, as measured by either technique, with age. Previous studies have shown that infant accommodation displays immaturities in terms of variability in the accommodative response slope and the amount of focus errors. Both of these immaturities tend to improve up to the age of 3 to 4 month, either reaching an adult level of performance,[20] or still showing occasional immaturity at 3 month.[21,23] Braddick et al. observed consistent focus behavior emerging between 3 and 6 month of age in response to a low accommodative demand of 1.3 D (75 cm).[13] Infants presented with greater accommodative demands generally showed improvement in the accommodative response slope with age, but not to adult levels even by the age of 5 month.[28,29] Howland et al. observed values for the accommodative response slope in infants of about 0.6 with no change with age between 2 and 7 month.[24] The current study found that infants have adult-like and stable accommodation by the age of 3 months once inattention during the use of the PR was removed as a large source of variability.

This finding has interesting implications for the mechanism driving the accommodative response. Most researchers subscribe to the "sensory hypothesis" of accommodative development which proposes that throughout infancy, improving visual acuity allows a better stimulus for accommodation, which in turn makes for a more accurate accommodative response. But, in this study, accommodative error did not change between 3 and 12 month of age, suggesting that accommodation is fully developed by 3 months. However, visual acuity improved between 3 and 12 month. This trend was similar to previous studies using TAC.[31,32] These results raise the question of how can accommodation be fully developed at 3 months if visual acuity is still improving until 12 months? If the sensory hypothesis is correct, then lag should have been correlated with visual acuity changes over a similar time course. One possible explanation is that the TAC technique could have underestimated visual acuity. Any visual acuity changes measured from 3 to 12 months may be the result of infants developing the skills necessary to perform the difficult preferential looking task rather than an actual improvement in visual acuity. This is supported by data showing that TACs measured a poorer visual acuity than VEP.[33] Another possibility is that measurement error for accommodation might hide subtle improvements with age. However, it seems unlikely that average acuity could improve by a factor of nearly three times due to improvements in accommodation without measureable changes in accommodative performance.

The results for test distance, gender, and SEQ distance RE showed some important and clinically relevant patterns. In general, accommodative error was greater by 0.39 D at the further test distance of 57 cm. This is contrary to previous literature which has found increased lag with increased accommodative demand.[20–22,24] Infants may have shown a more accurate response at the closer distance due to proximal accommodation. It is also possible that it was easier for the infant to attend to the closer target because it was done before the 57 cm measurement each time. Whatever the source of the difference, boys seemed to show the effect more than girls. Girls' accommodative error was more uniform at each distance whereas boys showed greater lag at 57 cm. This underscores the importance of testing at multiple distances, including infinity. In this dataset, near defocus was not significantly related to RE. Accommodative errors at either test distance appeared to carry no dose-related information regarding the underlying RE. Considering recent information about the temporal integration of emmetropization signals, periods of exposure to minimal defocus at near that averages about 0.50 D may override longer exposures to signals for change in RE.[34,35] Understanding the signals for human emmetropization obviously requires more data. This study is limited by being cross-sectional rather than longitudinal, by the small sample size, and by the limited range of REs.

In summary, MEM and PR provided similar estimates of accommodative error once the data were screened for inattention using a performance-based criterion. Individual calibration using slope, or slope and intercept, calculated by regression from data after application of monocular trial lenses was not effective in improving measurement validity. Accommodation was adult-like by 3 months of age and did not vary by age despite improvement in acuity and decreases in hyperopic RE with age. Males showed greater accommodative response slopes than females due to improved accommodation at 33 cm compared to 57 cm.

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