

Comparison of noncycloplegic and cycloplegic autorefraction in categorizing refractive error data in children

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ABSTRACT.

Purpose: To systematically analyse the differences between cycloplegic and noncycloplegic refractive errors (RE) in children and to determine if the predictive value of noncycloplegic RE in categorizing RE can be improved.

Methods: Random cluster sampling was used to select 6825 children aged 4–15 years. Autorefraction was performed under both noncycloplegic and cycloplegic (induced with 1% cyclopentolate drops) conditions. Paired differences between noncycloplegic and cycloplegic spherical equivalent (SE) RE were determined. A general linear model was developed to determine whether cycloplegic SE can be predicted using noncycloplegic SE, age and uncorrected visual acuity (UCVA).

Results: Compared to cycloplegia, noncycloplegia resulted in a more myopic SE (paired difference: $-0.63 \pm 0.65D$, 95% CI: -0.612 to $-0.65D$, 6017 eligible right eyes) with greater differences observed in younger participants and in eyes with more hyperopic RE and smaller AL. Using raw noncycloplegic data resulted in only 61% of the eyes being correctly classified as myopic, emmetropic or hyperopic. Using age and uncorrected VA in the model, the association improved and 77% of the eyes were classified correctly. However, predicted cycloplegic SE continued to show large residual errors for low myopic to hyperopic RE. Applying the model to only those eyes with uncorrected VA $<6/6$ resulted in an improvement ($R^2 = 0.93$), with 80% of the eyes correctly classified. A higher VA cut-off (i.e., $\leq 6/18$) resulted in 97.5% of eyes classified correctly.

Conclusion: Noncycloplegic assessment of RE in children overestimates myopia and results in a high error rate for emmetropic and hyperopic RE. Adjusting for age and applying uncorrected VA cut-offs to noncycloplegic assessments improves detection of myopic RE and may help in identifying myopic RE in situations where cycloplegia is not available but does not help in identifying the magnitude of refractive error and therefore is of limited value.

Key words: children – cycloplegic refraction – myopia – non cycloplegic refraction – refractive errors

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Introduction

In children, noncycloplegic refractions are prone to significant errors, largely due to an active accommodation response. Mostly, there is a myopic shift in refractive error leading to an overestimation of myopia or an underestimation of hyperopia and thus a biased classification of the refractive error of the eye (Zhao et al. 2004; Choong et al. 2006; Hu et al. 2015). Therefore, an assessment of the refractive error of the eye under cycloplegia is considered to be the standard for refractive error measurements in children (Morgan et al. 2015). However, many impediments remain to the use of cycloplegia in children, such as lack of availability of cycloplegic drops, lack of regulatory approval for the use of cycloplegics by opticians and optometrists and unwillingness of parents or caregivers to have their child subjected to cycloplegia due to inconvenience associated with blurred near vision. Moreover, some population-based studies and school screenings are unable to invest in cycloplegic assessments due to lack of resources, time, expense and issues with obtaining parental consent. In these situations, the widespread use of noncycloplegic refraction to determine ocular refractive error status continues (Williams

et al. 2008, 2015; Vitale et al. 2009; WU et al. 2015; Nartey et al. 2016; Rim et al. 2016).

Although noncycloplegic measurements are considered unreliable in determining the refractive error of an individual eye, it is of interest to determine if, with appropriate modelling, the data can aid in categorizing refractive error groups and in identifying populations at risk that need further evaluation with cycloplegic refraction. In this respect, a better understanding of the biological factors at play can improve our knowledge of the measurement bias. Indeed, a previous study found that age and baseline refractive error played a role but concluded that despite correcting for these factors, the individual RE were still variable (Hu et al. 2015). Because UCVA is relied upon to detect ocular disorders including RE, noncycloplegic autorefractometry was combined with UCVA to improve the sensitivity of noncycloplegic refraction in screening and further referral (Lai et al. 2013; Ma et al. 2013).

In this study, we undertook a large-scale investigation into the assessment of RE using cycloplegia *versus* noncycloplegia in young, mostly urban Chinese schoolchildren. We sought to determine whether certain individual- and eye-related factors could be used to better understand the relation between noncycloplegic and cycloplegic refractive error. In addition to the previously known factors of age and baseline refractive error, we included further variables that are commonly available to the practitioner such as UCVA and gender. Also, axial length/corneal curvature ratio was considered a better predictor than UCVA for the refractive state of the eye (He et al. 2015). Therefore, axial length and corneal topography were also included in the analysis.

Patients and Methods

Study population

Children aged 4–15 years were enrolled from 21 schools in two districts (Jiading and Songjiang) in the Shanghai region using a cluster sampling technique. A minimum sample of 150 participants for each age from 4 to 15 years was set with a minimum power of 90% at a 5% level of significance to detect a paired difference of at least $0.75 \pm 1.25D$ to

$0.3 \pm 0.5D$, the difference in magnitude being a function of age. The sample was estimated assuming a cluster design effect of 2.5 and a cluster size of 200 and a response rate of 85%. The study protocol was approved by the Institutional Ethics Committee of Shanghai General Hospital, Shanghai Jiaotong University and followed the tenets of the Declaration of Helsinki for experimentation on humans. Parents, guardians or caregivers of all children from the two districts were contacted and informed of the study purpose and procedures and written informed consent was obtained. Parents were invited to consent to cycloplegia, and those who agreed were enrolled in the study. If children were aged 10 years or older, a signed informed consent was also obtained from the children. The study was performed from November 2015 to January 2016.

Procedures

All children underwent the following procedures: UCVA, noncycloplegic autorefractometry, axial length measurement, intraocular pressure check (non-contact tonometer, NT-1000, Nidek, Japan), and slit-lamp examination followed by cycloplegia and cycloplegic autorefractometry.

Prior to cycloplegia, distance VA (uncorrected and with habitual correction if any) was determined using a mounted and illuminated E chart of the Early Treatment Diabetic Retinopathy study (ETDRS) charts (LCD backlit lamp, 400 cd/m², WH0701, Guangzhou Xieyi Weishikang) at 4 m using ambient room lighting. The lines on the chart ranged from 6/4.8 to 6/60 in 0.1 log MAR steps with 5 tumbling 'E' letters per line. Vision was recorded in decimal notation.

For cycloplegia, 0.5% proparacaine hydrochloride was first instilled in each eye, and after approximately 15–20 seconds, two drops of 1% cyclopentolate (Alcon, Fortworth, TX, USA) were instilled 5 min apart in each eye. After 25–30 min, eyes were checked for dilation and pupillary response to light. The eye was considered to be cycloplegic if the pupil was dilated to 6 mm or more and had no reaction to light. If needed, a third drop was instilled. Children were encouraged to keep their eyes closed if possible for the duration of cycloplegia.

Autorefractometry was performed using an autorefractor (KR-8900, Topcon, Tokyo, Japan) with an average of three consecutive readings used to record the refractive error status for each eye. Axial length was measured using an IOL MASTER (version 5.02, Carl Zeiss, Jena, Germany) with an average of three measurements considered for data analysis. If any two measurements varied by more than 0.50 dioptres with autorefractometry or 0.02 mm for axial length, the readings were discarded and the eye remeasured. For a given child, a single examiner conducted both the pre- and postcycloplegic measurements. Subjective refraction and best corrected visual acuity (BCVA) were determined only in children whose UCVA <6/7.5 in either eye, based on the values of the autorefractometry as the starting references. For the purpose of this analysis, UCVA data, cycloplegic and noncycloplegic refractive error measurements, axial length and corneal curvature measurements were considered.

Statistical analysis

Statistical analysis was performed only on normal eyes, which composed 91% of the complete dataset. Data from eyes with an ocular finding (for example, corneal scars), strabismus and narrow ACD were excluded from the analysis. Only right eyes were included in the analysis. Spherical equivalent (SE) was computed as sphere + half cylinder power. Initially, univariable analysis was performed to test for differences between noncycloplegic and cycloplegic SE using a paired *t*-test and was also considered in subgroups based on age, gender, refractive error, UCVA, axial length and average corneal curvature. A multivariable general linear model was developed to determine significant factors associated with cycloplegic SE (considered the gold standard). Factors that were found to be significant and not exhibiting significant intercorrelation were included in the final model along with noncycloplegic SE. Model *R* squared >85% was considered acceptable. Statistical significance was set at 5%. Additional analyses were conducted using the model but including only those eyes with suboptimal vision (i.e., <6/6 and ≤6/18) to determine if vision cut-off values improve the predictive value of noncycloplegic

assessments. Sensitivity, specificity and positive predictive values for each of the models in diagnosing myopia, emmetropia and hyperopia are presented.

Results

A total of 6825 children aged 4–15 years were examined in the study. Data from a total of 808 children were excluded as they either an ocular finding that was considered to influence refractive status (for example, corneal scar, strabismus or narrow-angle) or there were missing data from one or both eyes. Therefore, data from 6017 children (6017 right eyes) are presented in this analysis. Table 1 presents the demographic details (age and sex) for the eyes that were analysed. The baseline refractive error based on noncycloplegic SE refractive error ranged from +8.00 to –11.00D and based on cycloplegic SE refractive error ranged from +8.38D to –10.63D.

Mean difference between noncycloplegic and cycloplegic refraction

Overall, there was a mean paired difference of -0.63 ± 0.65 D (95% CI: -0.61 to -0.65 D) between noncycloplegic and cycloplegic SE refractive error, with the noncycloplegic refractive error resulting in a more myopic (or less hyperopic) refractive error. The

mean paired difference for sphere was -0.65 ± 0.64 D and for cylinder was -0.04 ± 0.28 D and were all significant ($p < 0.001$, paired *t*-test.).

Figure 1 illustrates the mean paired differences in noncycloplegic and cycloplegic refractive error by age, refractive error, gender, axial length, corneal curvature and UCVA. In all instances, noncycloplegic refraction resulted in a more negative (more myopic) refractive error. The difference was greatest with younger age, hyperopic RE and smaller axial length. Also, the difference was least in eyes with UCVA worse than or equal to 6/18 (0.26D). There was no significant impact of gender or corneal curvature on the difference between cycloplegic and noncycloplegic refraction.

Age was found to independently correlate with both baseline refractive error and baseline axial length (Fig. 2; $R^2 = 0.4$). However, because baseline refractive error and baseline axial length were highly correlated (Fig. 3; $R^2 = 0.58$), further analysis was conducted with inclusion of only baseline refractive error in the general linear model along with age and UCVA.

Correlation between noncycloplegic and cycloplegic refraction

Eyes were stratified into myopia ≤ -0.75 D, emmetropia (> -0.75 to

$< +0.75$ D) and hyperopia ($\geq +0.75$ D) (Table 2).

Prevalence based on cycloplegia was 28.7%, 28.2% and 43.1% for myopia, emmetropia and hyperopia, respectively. Prevalence based on noncycloplegia was 36.9%, 51.7% and 11.5% for myopia, emmetropia and hyperopia. Although a significant correlation was found between noncycloplegic and cycloplegic (*y*) SE ($y = 0.69 + (1.07x \text{ noncycloplegic SE})$, $R^2 = 0.90$), noncycloplegic autorefraction results in an overestimation of myopia by 28.5% and under estimation of hyperopia by 73% relative to cycloplegic autorefraction. Overall, only 61% of the eyes (99% of myopes, 78% of emmetropes and 26% of hyperopes) were correctly categorized with noncycloplegia. The sensitivity, specificity and positive predictive values are provided in Table 3. Figure 4A illustrates the correlation between cycloplegic and non cycloplegic SE.

When age and UCVA were input into the model, the strength of association improved slightly ($y = 0.831 + (0.954 \times \text{noncycloplegic SE}) + (-0.065x \text{ age}) + (0.539 \times \text{UCVA})$, $R^2 = 0.91$, where *y* = cycloplegic SE).

Prevalence based on the model was 27.3%, 31% and 41.7% for myopia, emmetropia and hyperopia. Using the model resulted in 77% of eyes being correctly categorized, with sensitivity, specificity and predictive values of 89.3%, 97.6% and 93.8% for myopes, 65.1%, 82.3% and 59% for emmetropes and 76.8%, 85% and 79.5% for hyperopia.

The absolute difference in prevalence obtained using the model *versus* the cycloplegic autorefraction was 1.4% and 1.5% for myopia and hyperopia, respectively. Figure 4B illustrates the correlation between predicted cycloplegic SE and observed cycloplegic SE, and Fig. 5 illustrates the residual RE (difference between observed and predicted cycloplegic SE) using a Bland Altman plot. The plot shows that the limits of agreement were wider for RE less than approximately -2.00 D towards hyperopia with the predicted SE overestimating myopia.

Further analyses were conducted using a reduced sample size based on cut-off values for VA $< 6/6$ and $\leq 6/18$. Using the same factors as before in the model, that is, age, noncycloplegic SE and UCVA, the predictability of the model improved ($y = 0.771 +$

Table 1. Baseline participant characteristics.

Characteristic	n = 6017
Age, mean \pm SD years; range years	9.1 \pm 2.9; 4–15
4 years, n (%)	425 (7.1)
5 years, n (%)	447 (7.4)
6 years, n (%)	700 (11.6)
7 years, n (%)	753 (12.5)
8 years, n (%)	801 (13.3)
9 years, n (%)	775 (12.9)
10 years, n (%)	703 (11.7)
11 years, n (%)	466 (7.7)
12 years, n (%)	229 (3.8)
13 years, n (%)	314 (5.2)
14 years, n (%)	189 (3.1)
15 years, n (%)	215 (3.6)
Male: Female, n (%)	3270 (54.3):2747 (45.7)
Spectacle wearing history, n (%)	
No, don't wear specs	4577 (76.1)
Yes, wear specs	980 (16.3)
Yes, forgot to bring specs	110 (1.8)
Noncycloplegic refraction (Dioptres)	
Mean \pm SD; range	-0.74 ± 1.79
Cycloplegic refraction (Dioptres)	
Mean \pm SD; range	-0.11 ± 2.02

SD = standard deviation.

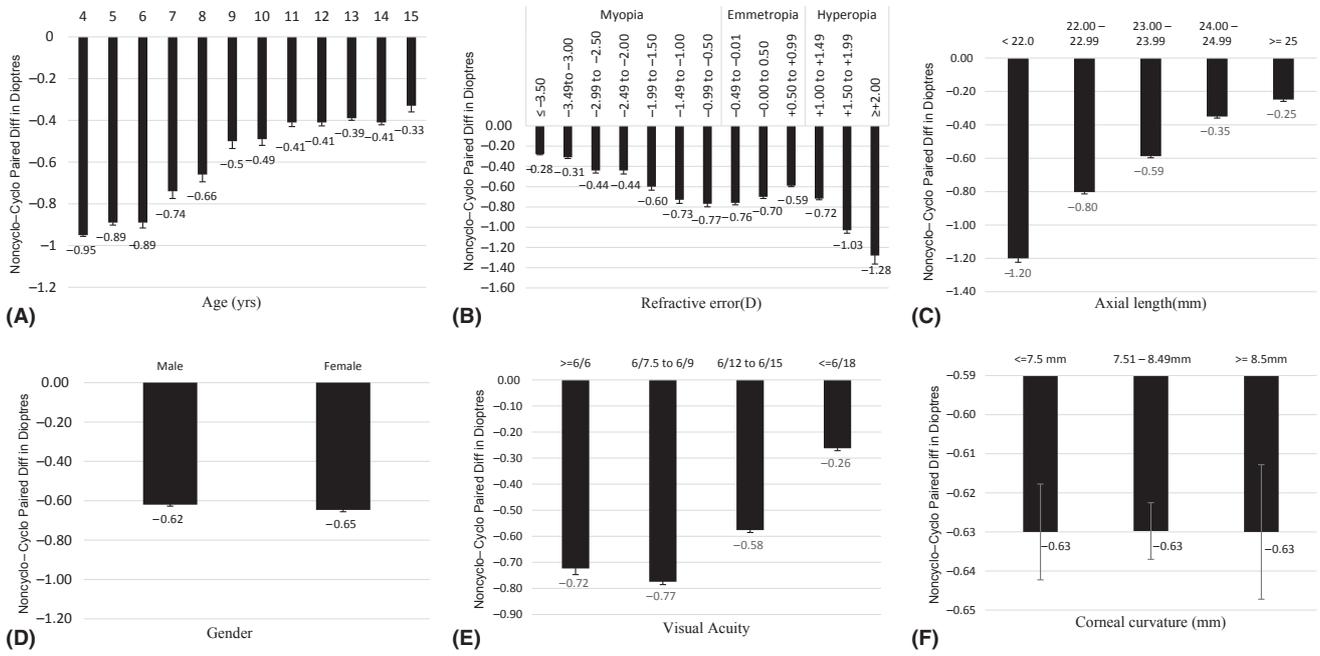


Fig. 1. Paired differences between noncycloplegic versus cycloplegic refractive errors based on age (A), refractive error (B), axial length (C), gender (D), uncorrected visual acuity (E) and corneal curvature (F).

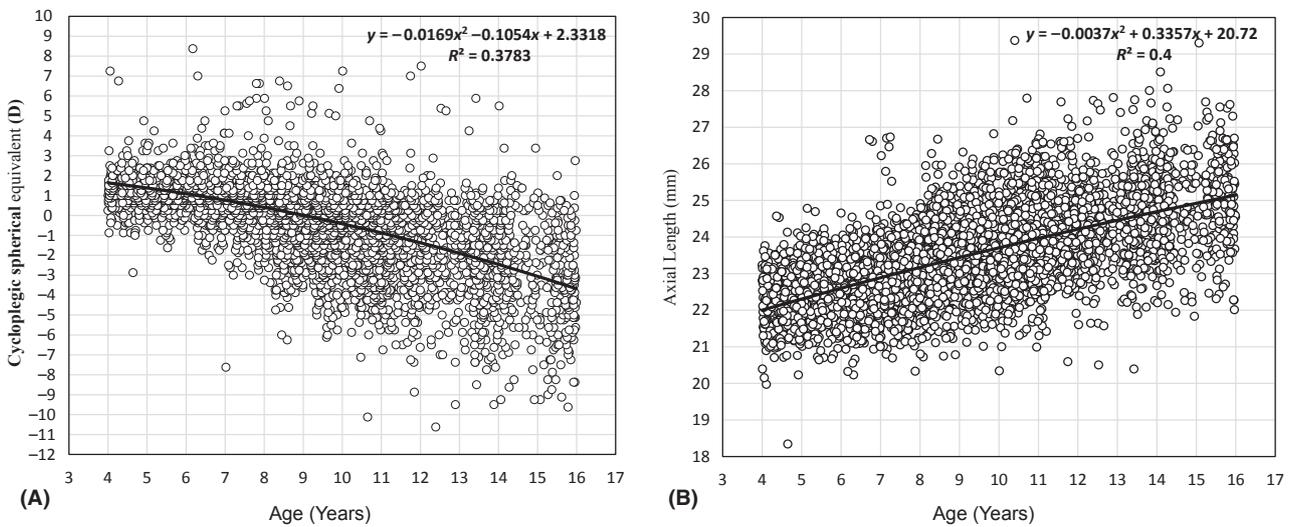


Fig. 2. Correlation between age and cycloplegic spherical equivalent (A) and axial length (B). D = dipotre.

$(0.977 \times \text{noncycloplegic SE}) + (-0.057 \times \text{age}) + (0.585 \times \text{UCVA}); R^2 = 0.93$.

For eyes with VA <6/6 ($n = 4616$), the prevalence of myopia, emmetropia and hyperopia using cycloplegic autorefraction was 36.9%, 23.4% and 39.8%. The prevalence of myopia, emmetropia and hyperopia using this model was 34.7%, 27% and 38.3%, respectively. Overall, 80% of the eyes were correctly categorized using this approach. Sensitivity, specificity and predictive values were 89.5%, 97.4% and 95.3% for myopia, 66.4%, 85%

and 57.4% for emmetropia and 79.8%, 89.1% and 82.9%, respectively, for hyperopia.

For eyes with VA $\leq 6/18$ ($n = 1262$), the prevalence of myopia, emmetropia and hyperopia using cycloplegic autorefraction was 94.1%, 2.2% and 3.7%. In this sample, as expected, the prevalence of emmetropia and hyperopia was low. Prevalence based on predicted cycloplegic SE using model was 95.6%, 1.7% and 2.7% respectively. In this subset, 97.5% of the eyes were correctly categorized. The sensitivity, specificity and predictive values of myopia was 100%,

73.3% and 98.3% for myopia, 32.1%, 99% and 42.9% for emmetropia and 72.3%, 100% and 100% for hyperopia.

Discussion

In alignment with previously published data, our results on Chinese, urban schoolchildren confirm that noncycloplegic assessment of refractive error results in a more myopic refraction compared to cycloplegic refraction, thus overestimating the incidence or prevalence of myopia and underestimating the prevalence of emmetropia

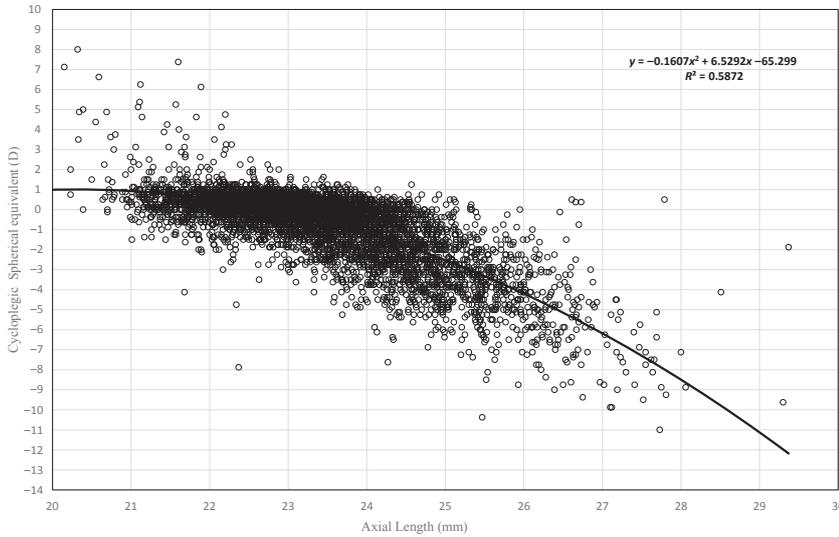


Fig. 3. Correlation between cycloplegic spherical equivalent and axial length.

and hyperopia. More importantly, our systematic analysis of paired differences between cycloplegic and noncycloplegic refraction across ages ranging from 4 to 15 years and all types of RE indicates that the overestimation of myopia with noncycloplegia is greater in younger individuals, in eyes with less myopic/more hyperopic refractive error, in eyes with smaller axial lengths and in eyes with better VA. Therefore, noncycloplegic assessments to determine the refractive state

of the eye are of poor value, especially for refractive errors of low magnitude (low myopia, emmetropia and low hyperopia) and high hyperopia.

Uncorrected visual acuity (UCVA) is said to provide a reasonably accurate estimate of prevalence of myopia (Leone et al. 2010). Adjusting for age and VA of the eye slightly improves the predictive value but there still remain a significant proportion of eyes that remain misclassified. Applying further distance VA cut-off values and

considering only those with less than optimal vision improved the predictive value of noncycloplegic refraction in categorizing RE as it reduced the risk of inclusion of eyes where there was an increased risk of misclassification, that is emmetropia, RE of low magnitude and eyes with no distance vision impairment (hyperopes). Such assessments may be of some value in understanding the prevalence of RE in populations especially where the prevalence of myopia is high as in the current population or in populations where skilled cycloplegic assessments are scarce. However, for any particular cycloplegic refractive error, the variability between eyes for the noncycloplegic refractive values indicates the difficulty in predicting cycloplegic refractive error. Therefore, noncycloplegic autorefractometry, at least with currently available technology, is of limited value in accurately determining the refractive status of a given individual eye.

Although increasing age, more myopic RE and a greater axial length reduced the dioptric difference between noncycloplegic and cycloplegic assessments, these factors in children are interdependent to a large extent because with age, RE tend to become less hyperopic and the axial length increases. Indeed, in our analyses there

Table 2. Observed prevalence and predicted prevalence.

	Cycloplegic refractive errors			Predicted prevalence	Overall classification rate
	Myope	Emmetrope	Hyperope		
Observed prevalence: all eyes	1726 (28.7%)	1695 (28.2%)	2596 (43.1%)		
Noncycloplegic data alone					
Myope <i>n</i> = 2218	1713	352	153	36.9%	61%
Emmetrope <i>n</i> = 3108	13	1316	1779	51.7%	
Hyperope <i>n</i> = 691	0	27	664	11.5%	
Model B					
Myope <i>n</i> = 1642	1541	81	20	27.3%	77%
Emmetrope <i>n</i> = 1868	183	1103	582	31%	
Hyperope <i>n</i> = 2507	2	511	1994	41.7%	
Observed prevalence: eyes with VA <6/6	1703 (36.9%)	1078 (23.4%)	1835 (39.8%)		
Model B					
Myope <i>n</i> = 1600	1525	60	15	34.7%	80%
Emmetrope <i>n</i> = 1248	177	716	355	27%	
Hyperope <i>n</i> = 1768	1	302	1465	38.3%	
Observed prevalence: eyes with VA ≤6/18	1187 (94.1%)	28 (2.2%)	47 (3.7%)		
Model B					
Myope <i>n</i> = 1180	1173	7	0	93.5%	97.7%
Emmetrope <i>n</i> = 39	14	19	6	3.1%	
Hyperope <i>n</i> = 43	0	2	41	3.4%	

* Myope ≤ -0.75D; Emmetropia: (> -0.75 to < +0.75D); Hyperope: ≥+0.75D. D = dioptre, VA = visual acuity.

Table 3. Sensitivity, specificity and positive predictive values.

	Diagnostic category	Sensitivity (95% CI)	Positive predictive value (95% CI)	Specificity (95% CI)
Noncycloplegic data alone	Myopia	99.2% (98.8–99.7%)	77.2% (75.5–79%)	88.2% (87.3–89.2%)
	Emmetropia	77.6% (75.7–79.6%)	42.3% (40.6–44.1%)	58.5% (57.1–60%)
	Hyperopia	25.6% (23.9–27.3%)	96.1% (94.6–97.5%)	99.2% (98.9–99.5%)
Model B	Myopia	89.3% (87.8–90.7%)	93.8% (92.7–95%)	97.6% (97.2–98.1%)
	Emmetropia	65.1% (62.8–67.3%)	59% (56.8–61.3%)	82.3% (81.2–83.4%)
	Hyperopia	76.8% (75.2–78.4%)	79.5% (78.0–81.1%)	85% (83.8–86.2%)
Model B in eyes with VA <6/6	Myopia	89.5% (88.1–91%)	95.3% (94.3–96.3%)	97.4% (96.9–98%)
	Emmetropia	66.4% (63.6–69.2%)	57.4% (54.6–60.1%)	85% (83.8–86.1%)
	Hyperopia	79.8% (78.0–81.7%)	82.9% (81.1–84.6%)	89.1% (87.9–90.3%)
Model B in eyes with VA ≤6/18	Myopia	100% (N/A)	98.3% (97.6–99.1%)	73.3% (63.3–83.3%)
	Emmetropia	32.1% (14.8–49.4%)	42.9% (21.7–64%)	99% (98.5–99.6%)
	Hyperopia	72.3% (59.6–85.1%)	100% (N/A)	100% (N/A)

CI = confidence interval, VA = visual acuity.

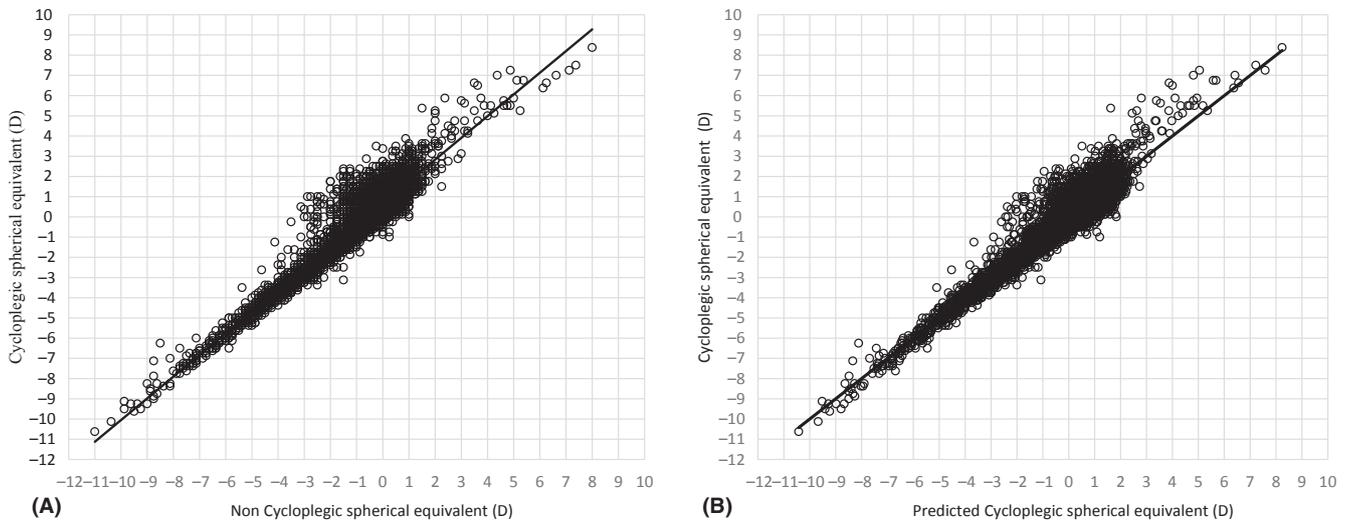


Fig. 4. Correlation between cycloplegic spherical equivalent and noncycloplegic spherical equivalent (A) and predicted cycloplegic spherical equivalent based on model (B). D = dioptre.

existed a significant correlation between baseline refractive error and axial length, and both of these factors had a significant correlation with age. In young children, the difference between noncycloplegic and cycloplegic refraction was nearly a dioptre (mean of $-0.95D$), whereas in the older children, this was seen to have reduced by more than half ($-0.33D$) but was still greater than the $0.25D$ that is considered to be a clinically relevant difference. The dioptric difference between cycloplegic and noncycloplegic assessments is likely explained by accommodative response to proximal cues during noncycloplegia. The gap between noncycloplegic and cycloplegic refraction was minimal in eyes with myopia greater than $-2.5D$ and in eyes with axial length >25 mm. This

finding supports the previous findings that myopic eyes show less accommodation for near targets, thus minimizing the difference between cycloplegic and noncycloplegic refraction (Millodot 2015). Some individual variability still exists, but where the refractive error is worse than $-2.00D$ with a noncycloplegic auto refractor, it is quite likely that the eye is actually myopic. However, with the less myopic eyes (including eyes with emmetropia, hyperopia and myopia less than approximately $-2.00D$), the individual variability precludes any assumption on the refractive status of the eye. While in theory, it may be feasible to adjust for the accommodative response of the eye, age-related norms for accommodative responses in eyes without significant refractive error suggest

that the accommodative response can be quite variable for high accommodative demands, especially in younger eyes (McClelland & Saunders 2004). For example, in 4-year-olds, for a $4D$ demand, the response ranged from $2.52D$ to $4.88D$. Given this variability in individual responses, it would be difficult to apply a normative factor adjusting for accommodative response. Therefore, without cycloplegia, it is difficult to predict the refractive error of a young eye. In this respect, it would be useful to consider other factors, such as UCVA, to determine if the child needs further evaluation with cycloplegia.

Our data showed a reduced difference in the older eyes between cycloplegic and noncycloplegic refraction, indicating a lower need for cycloplegia

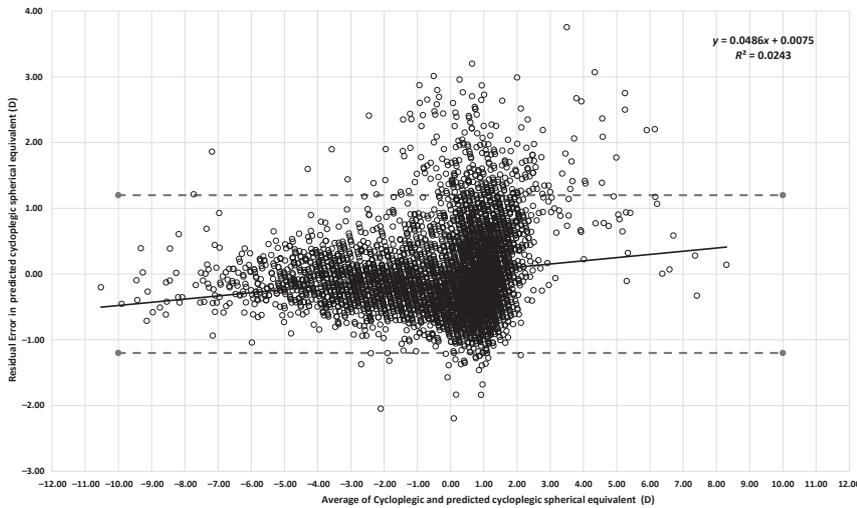


Fig. 5. Residual errors with predicted cycloplegic spherical equivalent refractive errors. D = dioptre.

for older individuals. In this respect, Fotouhi et al. (2012) found differences between manifest and cycloplegic refraction to persist well into adulthood (≥ 50 years). In contrast, it was said that the differences between cycloplegic and noncycloplegic refractions were clinically inconsequential in adults spanning a wide age range (22–84 years), although the differences were not uniform and differences were greater in younger emmetropic and hyperopic eyes (Krantz et al. 2010).

With all of the above, it should be noted that while a cycloplegic refraction is considered to be the standard in young children, a cycloplegic refractive state is not indicative of the normal physiological state of the eye due to alteration in the optical properties of the eye during cycloplegia. For example, refraction across a larger pupil aperture during cycloplegia may be influenced by the peripheral aberrations induced by refractive media (Hiraoka et al. 2014). Also with cycloplegia, differences in outcome exist with the amount and type of cycloplegic agent used and in pigmented versus nonpigmented eyes; thus, there is no single reliably consistent measure. A cycloplegic refractive error is thus a reference point that may need to be further refined to suit the needs of an individual eye.

In the current study, the observed prevalence of myopia ($\leq -0.75D$), emmetropia and hyperopia ($\geq +0.75D$) using cycloplegic refraction was 28.7%, 28.2% and 43.1%, respectively. Using raw noncycloplegic refractive values

alone, the prevalence of myopia, emmetropia and hyperopia was estimated to be 36.9%, 51.7% and 11.5% with only 62% of the eyes correctly classified into their respective categories. Sensitivity in diagnosing myopia was high but was particularly poor at 25.6% for hyperopia, indicating that many more of the hyperopic eyes were misclassified as either emmetropes or myopes. Adjusting the noncycloplegic autorefraction data by combining with age and VA as in model B slightly improves the positive predictive value for both myopia and hyperopia; however, the per cent of the eyes that remain misclassified is nearly 23%. When only eyes that had vision less than 6/6 were considered, and there was a further slight improvement. Additionally, in the current study population, the prevalence of moderate to high hyperopia is low. Thus, a limitation of this model is that the equations or corrective factors used in these models are more applicable to populations wherein myopia is more prevalent and hyperopia is seen in few. Therefore, use of this model is not appropriate to categorize refractive error prevalence in non-Asian countries or certain ethnic populations where the prevalence of myopia may not be high. In addition, it may also not be valid specifically for the very young populations where hyperopia may be the predominant refractive error. Additionally, while in the current study, cut-off values of $\geq +0.75D$ for hyperopia and $\leq -0.75D$ for myopia were used, and using other cut-off values may vary the predictive value of the

models. Although there was a significant improvement when eyes with vision $\leq 6/18$ were considered, it needs to be recognized that such cut-offs only consider those with significant RE and therefore limits the applicability of this model to estimate prevalence of RE in the general population. In addition, in the current analysis, the prevalence of significant hyperopia was quite low.

In the current study, we used two drops of 1% cyclopentolate, a widely used cycloplegic agent in studies considering RE in children (Fotedar et al. 2007; Wu et al. 2013; McCullough et al. 2016). In addition, the protocol allowed an additional drop in eyes that were deemed to be not sufficiently cyclopleged. One limitation of the current study was that the end-point of achievement of cycloplegia was based on the examiner’s recording and not assessed by any objective measure. Thus, we cannot confirm that cycloplegia was fully achieved in all eyes in the study. Additionally, when performing noncycloplegic refraction, many factors such as the room illumination, instructions provided to the child and the technique used by the examiner may impact on the way the child relaxes their accommodation. These factors were not controlled in the present study and consequently may have accounted for some of the variability seen between the cycloplegic and noncycloplegic data. Furthermore, we have evaluated the difference between cycloplegia and noncycloplegia using a single autorefractor, a Topcon KR-8900. It is known that the size and type of target influences the accommodative response and thus the values obtained with noncycloplegia may differ from instrument to instrument (Suryakumar & Bobier 2003). As the goal of the current study was to determine the utility of noncycloplegic autorefraction in determining the refractive status of the eye, we did not perform a binocular subjective refraction. Because the study included quite young children whose subjective response is less predictable than younger adults, we did not consider subjective refraction as the end-point for comparison.

In summary, the present study has demonstrated that in children, noncycloplegic autorefraction has limited value in determining the refractive status of the eye, especially for

hyperopes and therefore cycloplegia remains essential. In populations where the prevalence of myopia is generally high, when used in conjunction with VA cut-offs, noncycloplegic refractive error may aid in determining if an eye is myopic but a further evaluation with cycloplegic refraction is required for determining the magnitude of the refractive error of the eye.

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