Original Research

An Evaluation of Binocular and Accommodative Function as Predictors of Myopia Progression

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Abstract

Introduction
This study was designed to evaluate whether common tests of binocular and accommodative function can predict myopia progression in children. The study explored lesser-studied clinical measures beyond accommodative lag and phoria.

Methods
This retrospective cohort study reviewed patients from age 5 years 0 months up to but not including the 17th birthday in an urban academic U.S. clinic. We measured binocular and accommodative functions in a sample of 410 patients with normal corrected visual acuity. The functions were correlated to change in cycloplegic refraction over time.

Results
The mean observation period was 2.59 ± 0.70 years. Pearson's correlation coefficients between binocular/accommodative measures and refractive change were weak (r = -0.02 to 0.03). Excluding patients with constant strabismus and stratifying by phoria type (exodeviation or esodeviation), along with fusional vergence metrics, failed to make any meaningful improvements (r = -0.10 to 0.07). Even among patients at high-risk for myopia and myopia progression (baseline refraction ≤ 0.75D), correlations remained weak (r = -0.12 to 0.06).

Conclusion
In this clinic sample, common tests of binocular vision and accommodation were independent of change in refractive error and did not discriminate future myopia conversion or progression.

Key words
Myopia, binocular vision, accommodation

Introduction

The frequency and severity of myopia has increased, especially in children, for several decades and is expected to continue to rise.[1,2] The major nonclinical risk factors include parental history, family origin, time spent indoors, and amount of visual near work activities (e.g., reading, computer, tablet, smartphone use).[3-14] Of these, parental history has the highest association.

Clinical risk factors for myopia progression include age at onset, magnitude of myopia, axial length, accommodation to convergence ratio, accommodative lag, corneal power, and lens thickness.[3,4,6,15] Of these, magnitude of myopia at ages 6–8 years has been shown to be the single best predictor for myopia progression.[4] As noted in the Collaborative Longitudinal Evaluation of Ethnicity and Refractive

Suggested citation
Hatch SW. An Evaluation of Binocular and Accommodative Function as Predictors of Myopia Progression. *Canadian Journal of Optometry*. 2025;87(3):27-33. DOI : 10.15353/cjo.v87i3.6384

Error (CLEERE) study: "Children with a younger age of onset had higher rates of myopia progression (0.58D per year for onset at age 7 versus 0.16D per year for onset at age 13)."[4] Introducing additional weak but statistically significant variables, such as accommodation to convergence ratio, accommodative lag, corneal power, and lens thickness, improved prediction slightly.[4]

Some studies on accommodation found insufficient accommodative response correlated with the magnitude of myopia.[16-19] Other studies found accommodative response not to be predictive of myopia or myopia progression.[20,21] Goss and colleagues published a series of articles on clinical characteristics of children aged 6-15 years who converted to myopia compared to those who remained emmetropic.[19,22,23] The variables associated with myopia development were lower binocular accommodative amplitude (measured by minus lens stimulation), esophoria, higher convergence blur point at near, and larger accommodative lag.

Subsequent clinical trials demonstrated that wearing multifocal spectacle lenses can slow childhood myopia progression in certain cases, such as in the presence of esophoria (average of 0.14D less progression over 18-36 months of wear).[24] The Correction of Myopia Evaluation Trial (COMET) study found that children with high accommodative lag and esophoria who wore multifocal spectacles progressed an average of 0.64D less than a matched group wearing single vision distance correction over a 3-year observation.[25] Whether the differences were from effects on accommodative lag, amplitude of accommodation, esophoria, or a combination of these functions is unknown.

To summarize known clinical risk factors, the magnitude of myopia at ages 6-8 years is the best predictor of the magnitude of myopia in future years, while other clinical measures add only modest improvements to a predictive model. Some studies provide relatively strong evidence for the role of binocular and accommodative functions, specifically accommodative response and esophoria, while others found little evidence.

Myopia control treatments have increased in popularity among eye care providers and patients. The methods most researched include orthokeratology, multifocal distance centre hydrogel contact lenses, low dose atropine, red light therapy, and defocus incorporated multiple segments spectacle lenses (DIMS).[24,26] Each of these slow myopia on average. In a previous report from this data set, 80% of those with emmetropia and 67% of those with hyperopia of 0.75D or less converted to myopia.[27] Would it be appropriate to offer myopia control to such patients? Not all children with myopia are progressors, and not all children with emmetropia or low hyperopia convert to myopia. The purpose of this study is to determine if common binocular and accommodative measures can predict myopia conversion or progression. Specifically, several measures not previously studied but easily incorporated into the routine eye exam were evaluated with respect to refractive change. These measures were made across all refractive errors and ocular alignments, then stratified based on:

- refractive errors at highest risk of myopia progression;
- exophoria and esophoria.

Methods

We chose the SARS-2-CoV pandemic for the observation period due to increases in the frequency of myopia in this clinic's population. The increases in myopia may be secondary to the shift to online learning, less time outdoors, and/or increased digital device use.[14,27]

An independent ethical review board reviewed this research, and it conforms with the principles and applicable guidelines for the protection of human subjects in biomedical research. Specifically, by expedited review, the Salus University Institutional Review Board approved the project as exempt under U.S. federal regulation 45CFR 46.104 Section 4.ii.

Records of all patients aged 5 years 0 months up to but not including the 17th birthday who presented to the Pediatric and Binocular Vision Service at The Eye Institute (Philadelphia, PA, U.S.) for comprehensive eye exams from and including March 1, 2019, through February 29, 2020, were reviewed. Table 1 lists inclusion and exclusion criteria.

Baseline data (exposures) and outcome data extracted from the 2019-2020 comprehensive exams are listed in Table 2. All subject data were de-identified. The frequency of refractive errors at baseline were hyperopia 62%, emmetropia 2%, and myopia 36%. The frequency of refractive errors at

Table 1. Criteria for cohort membership

Inclusion	Exclusion
• Age 5 years 0 months to 16 years 11 months up to but not including the 17th birthday • Able to provide verbal or matching visual acuity on a Snellen, Lea, HOTV, or early treatment of diabetes retinopathy study chart • Best corrected visual acuity 20/30 (6/9) or better each eye • Comprehensive eye exam including cycloplegic refraction completed • Subsequent comprehensive exam completed including cycloplegic refraction > 1 year after baseline exam	• Amblyopia defined as best corrected visual acuity worse than 20/30 (6/9) either eye or a two-line or greater difference between the eyes in the presence of an amblyogenic factor • History of any of the following myopia control treatments: low-dose atropine, multifocal contact lenses, or orthokeratology • A diagnosed ocular condition that could affect central visual acuity • Manifest nystagmus in primary gaze

Table 2. Exposure variables collected at baseline pre-pandemic exams

Variable
Date of exam
Age
Observation time
Cycloplegic refraction
Cover test at distance
Cover test at near
Near point of convergence break point
Near point of convergence recovery
Divergence at near (blur, break, and recovery)
Convergence at near (blur, break, and recovery)
Accommodative amplitude each eye

outcome were hyperopia 54%, emmetropia 2%, and myopia 44%. Binocular and accommodative practice guidelines for examiners are from Scheiman and Wick.[28] Briefly, standard operating procedures were to conduct binocular and accommodative tests with the noncycloplegic refraction in a trial frame or through the habitual correction if no significant change in spectacle prescription was anticipated. Near point of convergence was measured with a 0.18 logMAR (20/30, (6/9)) accommodative target that was moved from 40 cm towards the spectacle plane until the patient reported diplopia or the observer saw one eye turn out. Negative fusional vergence (base-in break) at near was typically measured with the same target and a prism bar. The lowest power base-in prism was placed in front of an eye and increased until the patient reported diplopia or the observer noticed loss of alignment. Positive fusional vergence (base-out break) at near was performed in the same manner but utilizing base-out prism. Monocular amplitude of accommodation was measured with the same accommodative target placed within 2 cm of the eye and then moved away until the patient could read the letter(s).

Standard procedures for cycloplegia in the service during the study period was to use one or two drops of 1% cyclopentolate in new patients, established patients with strabismus, and established patients with esophoria. Tropicamide 1% at the examiner's discretion could be used for established patients with myopia, emmetropia, or low hyperopia without esotropia or esophoria. Spherical equivalent refractive errors of right eyes were used in the calculations. Likewise, only data from right eyes were used for monocular function (e.g. amplitude of accommodation). Access to the original data may be obtained by contacting the author.

Results

The total qualifying number in the cohort equaled 410 patients with a mean observation time of 2.59 years (±0.70). Refractive data and amplitudes of accommodation are reported for the right eye only. Sample size and correlation coefficient for each bin-

Table 3. Pearson's correlation coefficient (*r*) of clinical measure and change in spherical equivalent of cycloplegic refraction of right eyes

Independent variable	*n*	*r*
Cover test distance	401	-0.02
Cover test near	403	-0.01
Cover test distance excluding constant strabismus	396	-0.02
Cover test near excluding constant strabismus	398	0.01
Near point of convergence break point	387	-0.01
Near point of convergence recovery	382	-0.02
Amplitude of accommodation right eye	373	0.03

Table 4. Secondary analyses of patients with esophoria or intermittent esotropia (patients with constant strabismus excluded)

Independent variable	*n*	*r*
Cover test distance (magnitude of deviation)	167	-0.01
Cover test near (magnitude of deviation)	168	-0.01
Negative fusional vergence break point at near	151	-0.05
(Negative fusional vergence break point at near)/(magnitude of esophoria or intermittent esotropia)	168	-0.07
Accommodative amplitude of right eye	152	0.02

Orthophoria is included in esophoria because the average near phoria is slightly exophoric.[29]

ocular vision test prior to stratification by phoria and baseline refraction are presented in Table 3. The number of subjects reported for each test within the tables varies. Some tests could not be performed on all patients. For example, vergences cannot be performed on patients with constant strabismus. Some children refused certain tests or did not understand them sufficiently, and parameters for a few exams were simply not measured or not recorded.

Because binocular status may affect accommodation and possibly myopia progression, secondary analyses excluded patients with constant strabismus at distance or near. Data were then stratified by direction of deviation. The stratified results are presented in Tables 4 and 5. Orthophoria was combined with esophoria because normal alignment at near is slightly exophoric.[28]

Table 6 lists the correlations of binocular and accommodative functions with change in cycloplegic refraction in high-risk patients, those with baseline refractive error ≤0.75D.

Discussion

The biggest risk factors for myopia progression are age at onset, magnitude of myopia, and parental history of myopia.[3-12] Previous reports have found some relationships between specific binocular (esophoria) and accommodative functions (accommodative amplitude and response).[16-19,22,23] Furthermore, subjects with esophoria who were prescribed a near add had on average slower myopia progression than those in single vision spectacles.[23-25] In this sample, phoria as measured by cover test with refractive correction did not correlate with myopia progression (r = 0.03 for all phoria or intermittent strabismus types and r = -0.01 for esophoria only). To investigate further, the ratio of near negative fusional vergence divided by phoria was analyzed with myopia progression. Better negative fusional vergence suggests less tendency toward higher accommodative lag, a risk factor for myopia and myopia progression.[23-25] The resulting correlation (r = -0.05) shows this is clearly not the case in this sample.

The same analysis was performed for the ratio of near positive fusional vergence break point divided by the amount of exophoria. Failing Sheard's criteria (a ratio <2.0) is a predictor of symptomatic convergence insufficiency.[28] Subjects with higher ratios are more likely to meet Sheard's criteria and therefore have less blur (accommodative dysfunction) and are perhaps better protected against myopia. Again, no correlation with the amount of exophoria (r = 0.03) or ratio of positive fusional vergence to exophoria was found (r = 0.03).

Deficient amplitude of accommodation and inadequate near point of convergence blur point have also been correlated with myopia progression in other studies.[16-19, 22,23] In this sample, refractive

Table 5. Secondary analyses of patients with exophoria or intermittent exotropia (patients with constant strabismus were excluded)

Independent variable	*n*	*r*
Cover test distance (magnitude of deviation)	118	-0.10
Cover test near (magnitude of deviation)	230	0.03
Near point of convergence break point	223	-0.01
Near point of convergence recovery point	217	-0.07
Positive fusional vergence break point at near	213	-0.08
(Positive fusional vergence break point at near)/(magnitude of exophoria or intermittent exotropia)	213	0.03
Accommodative amplitude right eye	213	0.05

Table 6. Binocular and Accommodative Measures Correlated to Myopia Progression Right Eyes in Patients Whose Baseline Cycloplegic Refraction Was ≤ 0.75D (Patients With Constant Strabismus Were Excluded)

Independent variable	*n*	*r*
Cover test distance	235	-0.02
Cover test near	236	0.01
Near point of convergence break point	225	-0.04
Near point of convergence recovery point	225	-0.07
Negative fusional vergence break point at near	217	-0.12
Positive fusional vergence break point at near	216	-0.09
Amplitude of accommodation	215	0.06

changes were independent of near point of convergence and accommodative amplitude even after analyzing esophoria and exophoria separately. In addition, correlations were calculated for those who were at greatest risk for myopia conversion or progression — patients whose baseline cycloplegic refractions were 0.75D or less.[27] Again, correlations were essentially zero (Table 6).

In other studies, accommodative lag was predictive of myopia development.[16-19] In the present study, accommodative lag was not routinely measured, so its correlation with myopia conversion or progression could not be calculated. Higher accommodative lag is usually seen in esophoria at near and accommodative insufficiency.[28] The data presented here did not show an association between either esophoria at near or accommodative insufficiency and myopia progression; a result similar to that found by Price et al.[20]

Why the lack of correlation between binocular vision and accommodative parameters in this sample compared to most previous publications? Myopia across all ages was common in this sample, so children with myopia were not underrepresented. The patient population at The Eye Institute in Philadelphia is predominantly African American with small numbers of Asian and White children. East Asian children have the highest incidence and progression of myopia though it is certainly not rare in African American children.[4,5] Racial differences are possible explanations. However, there are no known differences in mechanisms for myopia between races or differences in binocular and accommodative functions.

The most significant difference regarding this sample is the timing. The present study is the only group observed during the SARS-2-CoV pandemic when children went to remote learning. Furthermore, most of the previous studies on binocular and accommodative predictors were performed before the introduction of smartphones and digital tablets. Whether digital screen exposure is biologically different from reading books and writing on paper for myopia development remains controversial, but most would agree that the duration of near vision exposure has dramatically increased in recent years. How digital device exposure might alter the relation between binocular and accommodative functions over time and their relation to myopia progression is a question for further research.

Limitations

Data from a clinic population may not be comparable to children in a general population, and an academic clinic may not be representative of primary eye care practice. One cannot rule out a role for binocular and accommodative functions not inves-

tigated, such as accommodative lag, accommodative facility, vergence facility, and others that were not present in sufficient numbers for analysis. Axial length was not available in the majority of patients. Cycloplegic agent used and timing of refraction after instillation of drops was not recorded, so some measurement error is possible. It is unlikely that these random measurement variations would contaminate the results because they should be equally distributed between baseline and outcome exams. In other words, the proportion and amounts of potential incomplete cycloplegia would be expected to be the same at baseline and outcome. Thus, there should not be a directional net effect toward higher or lower myopia. Some will argue that only 1% cyclopentolate provides adequate cycloplegia. The evidence, however, does not support this argument. Tropicamide 1% is an equally effective cycloplegic in myopia.[29,30] Even in subjects with hyperopia, the difference between tropicamide and cyclopentolate is less than 0.50D.

Conclusions

In this urban U.S. academic clinic, binocular and accommodative measures did not predict myopia progression. Parental history, age at onset, and magnitude of myopia remain the best predictors of myopia progression.

Disclosures

Acknowledgments: none

Data are available on a shared Google sheet. Email a request to the author.

Funding: none

Financial Disclosures or Conflicts of Interest: none. ICMJE uniform disclosure form completed.

Ethical Approval: Salus University Institutional Review Board approved the project as exempt under U.S. federal regulation 45CFR 46.104 Section 4.ii. The study complies with the tenets of the Declaration of Helsinki for research on human subjects.

Patient Consent Statement: Not applicable. Retrospective study classified exempt from US Common Rule. All data were de-identified.

AI Statement: The author confirms no generative AI or AI-assisted technology was used to generate content.

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