AMERICAN ACADEMY™ OF OPHTHALMOLOGY

Uncorrected Hyperopia and Preschool Early Literacy

Results of the Vision in Preschoolers—Hyperopia in Preschoolers (VIP-HIP) Study

*The VIP-HIP Study Group**
Writing Committee: Marjean Taylor Kulp, OD, MS,[1] Elise Ciner, OD,[2] Maureen Maguire, PhD,[3] Bruce Moore, OD,[4] Jill Pentimonti, PhD,[5] Maxwell Pistilli, MS,[3] Lynn Cyert, PhD, OD,[6] T. Rowan Candy, PhD,[7] Graham Quinn, MD, MSCE,[8] Gui-shuang Ying, PhD[3]

Purpose: To compare early literacy of 4- and 5-year-old uncorrected hyperopic children with that of emmetropic children.

Design: Cross-sectional.

Participants: Children attending preschool or kindergarten who had not previously worn refractive correction.

Methods: Cycloplegic refraction was used to identify hyperopia (≥3.0 to ≤6.0 diopters [D] in most hyperopic meridian of at least 1 eye, astigmatism ≤1.5 D, anisometropia ≤1.0 D) or emmetropia (hyperopia ≤1.0 D; astigmatism, anisometropia, and myopia <1.0 D). Threshold visual acuity (VA) and cover testing ruled out amblyopia or strabismus. Accommodative response, binocular near VA, and near stereoacuity were measured.

Main Outcome Measures: Trained examiners administered the Test of Preschool Early Literacy (TOPEL), composed of Print Knowledge, Definitional Vocabulary, and Phonological Awareness subtests.

Results: A total of 492 children (244 hyperopes and 248 emmetropes) participated (mean age, 58 months; mean ± standard deviation of the most hyperopic meridian, +3.78±0.81 D in hyperopes and +0.51±0.48 D in emmetropes). After adjustment for age, race/ethnicity, and parent/caregiver's education, the mean difference between hyperopes and emmetropes was −4.3 ($P = 0.01$) for TOPEL overall, −2.4 ($P = 0.007$) for Print Knowledge, −1.6 ($P = 0.07$) for Definitional Vocabulary, and −0.3 ($P = 0.39$) for Phonological Awareness. Greater deficits in TOPEL scores were observed in hyperopic children with ≥4.0 D than in emmetropes (−6.8, $P = 0.01$ for total score; −4.0, $P = 0.003$ for Print Knowledge). The largest deficits in TOPEL scores were observed in hyperopic children with binocular near VA of 20/40 or worse (−8.5, $P = 0.002$ for total score; −4.5, $P = 0.001$ for Print Knowledge; −3.1, $P = 0.04$ for Definitional Vocabulary) or near stereoacuity of 240 seconds of arc or worse (−8.6, $P < 0.001$ for total score; −5.3, $P < 0.001$ for Print Knowledge) compared with emmetropic children.

Conclusions: Uncorrected hyperopia ≥4.0 D or hyperopia ≥3.0 to ≤6.0 D associated with reduced binocular near VA (20/40 or worse) or reduced near stereoacuity (240 seconds of arc or worse) in 4- and 5-year-old children enrolled in preschool or kindergarten is associated with significantly worse performance on a test of early literacy. *Ophthalmology 2016;123:681-689 © 2016 by the American Academy of Ophthalmology.*

See Editorial on page 676.

Hyperopia of at least +3.00 diopters (D) occurs in 4.4% to 14.1% of preschool children.[1,2] Because accommodative amplitude is greatest in childhood, some argue that moderately hyperopic children generally have sufficient accommodation to allow sustained close work,[3] and others argue that the requirement for extra accommodative effort in the uncorrected hyperopic child may result in eyestrain, headache, intermittent blur, and difficulty attending at near conditions, as well as subsequent reading and school performance problems.[4–6] Although young children have been thought to have high levels of accommodation, recent research has shown that the amplitude of accommodation of young children might be lower than previously believed.[7] In addition, preschool children have less accurate accommodation than adults, and accommodative lag increases and becomes more variable with increasing demand.[8] Even children with mild hyperopia may not be able to compensate in the presence of accommodative insufficiency.[3] In these cases, the extra accommodative effort required to overcome a hyperopic demand with secondary eyestrain, intermittent blurring of letters, headaches, fatigue, and inefficient visual function may make learning and reading more difficult.[4–6]

Hyperopia is associated with decreased visuocognitive ability, reading ability, and visual attention in young children.[4–6,9–18] Studies have linked hyperopia and reading ability in school-aged children,[4–6,11–16] but with conflicting

http://dx.doi.org/10.1016/j.ophtha.2015.11.023
ISSN 0161-6420/15

results.[19] Results of a pilot study by Shankar et al[18] suggested that the association between hyperopia and reading ability may begin in preschool. The authors found reduced performance on tests of emergent literacy (letter and word recognition, receptive vocabulary, and emergent orthography) in 13 children with uncorrected hyperopia (≥2.00 D) versus 19 emmetropic children (≤1.50 D), but found no differences in phonological awareness, visual-motor integration, or visual-spatial skill.

Literacy development is currently viewed as a process that begins early in childhood.[20] Therefore, experiences in early childhood classrooms are often young children's first exposures to key early literacy building blocks. Of note, in today's early childhood classroom, there has been a shift away from more informal activities (e.g., manipulation of real-world objects) to earlier emphasis on formal literacy and academic work.[21] In addition, computer literacy and use that require sustained accommodative effort have become increasingly prevalent among preschool children compared with past generations. Furthermore, children entering kindergarten or first grade are expected to have knowledge of vocabulary, phonological awareness, and print knowledge.[22] Therefore, the educational achievement requirements and visual demands for preschoolers are rapidly increasing in today's society. To provide young children with the visual skills to meet these early academic challenges along with the best possible vision care, it is important to better understand any effects of uncorrected hyperopia on early educational performance.

The purpose of the Vision In Preschoolers—Hyperopia in Preschoolers (VIP-HIP) study was to determine whether uncorrected hyperopic (≥3.0—≤6.0 D) 4- or 5-year-old children without strabismus or amblyopia perform worse on an assessment of early literacy (Test of Preschool Early Literacy [TOPEL]) than comparable emmetropic children. The relationship between moderate hyperopia and early educational performance was further investigated by evaluating accommodative response and visual function (binocular near visual acuity [VA] and near stereoacuity) as possible associations in any relationships found between hyperopia and early literacy.

Methods

Children aged 4 or 5 years who were attending preschool or kindergarten and who had not previously worn correction for refractive error were invited to participate. Study participation included 2 visits, an eligibility eye examination, and an educational assessment. Candidates for the study were identified through screening programs in preschools and kindergartens that included a screening test of refraction. Children likely meeting the eligibility criteria for refractive error on the basis of their screening results and meeting the age criterion of 4 or 5 years on the date of the eligibility eye examination were invited to take part in the study. Whenever possible, hyperopic and emmetropic candidates were recruited from the same class, class level, or school at approximately the same time of the school year. Children with an individualized education program for developmental, educational, or behavioral issues were excluded. Institutional review board approval for the study and parental informed consent were obtained before performing any study procedures. The study adhered to the tenets of the Declaration of Helsinki.

Eligibility eye examinations were performed at a participating clinical center (Pennsylvania College of Optometry at Salus University, Philadelphia, PA; The Ohio State University College of Optometry, Columbus, OH; or New England College of Optometry, Boston, MA) or in specially equipped Vision in Preschooler vans[23] that provided an environment similar to the examination rooms at the centers. The eye examinations were performed by study-certified licensed eye care professionals experienced in working with young children. Testing included monocular distance threshold VA (ATS protocol)[24] and binocular near VA at 40 cm (single-surrounded HOTV optotypes, ATS4 Near Acuity Test; Precision Vision, Chicago, IL). Near VA was assessed according to the ATS4 protocol[25] with the exception that the child was tested binocularly to obtain a measure of the child's clarity of near vision under habitual near conditions. Near stereoacuity was evaluated at 40 cm using the Preschool Assessment of Stereopsis with a Smile, which is a 2-alternative, forced-choice, random dot test of near stereopsis. The child is presented a blank card (random dot pattern only) paired with a test card (demo, 480″, 240″, 120″, 60″, 40″, and 30″ levels) and asked to point to the card with the smiling face. Correct identification was required for 4 of 4 or 4 of 5 trials at each level. Testing was administered as previously described[26] with the exception of adding 40″ and 30″ levels. Additional assessments included accommodative response at 33 cm (measured with the Grand Seiko Autorefractor (AIT Industries, St. Bensenville, IL) [closest meridian to the target] and Monocular Estimation Method dynamic retinoscopy [horizontal meridian] while children viewed a naturalistic target [detailed sticker of a popular cartoon character]). Cycloplegic Retinomax (Righton, Tokyo, Japan) autorefraction was performed 30 to 45 minutes after administration of 2 drops of 1% cyclopentolate and was used to determine the eligibility of children for having a hyperopic (≥3.0—≤6.0 D in the most hyperopic meridian of at least 1 eye with astigmatism ≤1.5 D and anisometropia ≤1.0 D) or emmetropic (hyperopia ≤1.0 D, astigmatism <1.0 D, anisometropia <1.0 D, and myopia <1.0 D) refractive error. We retested VA with full correction after cycloplegia in children with reduced VA on initial testing (VA worse than 20/40 or 2 lines or more worse than the contralateral eye) to rule out amblyopia. Children with suspected amblyopia or strabismus were excluded from further participation in the study.

Eligibility criteria are shown in Table 1. Children confirmed to be eligible were scheduled for an educational assessment with a study-certified educational assessor on a different day, ideally scheduled within 3 weeks of the eye examination and no more than 3 months later. The TOPEL was selected as the primary outcome measure for assessing literacy on the basis of recommendations of the National Early Literacy Panel[22] and consultation with educational specialists during the development of the VIP-HIP study design. The test has documented evidence of validity and reliability, and meaningful norms.[20] The TOPEL has been used in large national studies, particularly those that evaluated the effectiveness of early childhood education programs. Valid assessments may be obtained by testers without extensive prior training, and the time burden on participants is acceptable.[20] The test is designed to identify preschoolers who are at risk for literacy problems by assessing prerequisite skills for developing reading proficiency.[20] The testing, consisting of Print Knowledge, Definitional Vocabulary, and Phonological Awareness subtests, was administered by trained examiners according to the published directions. Results of the 3 subtests are combined to determine a total score representing the child's emergent literacy skills. The overall mean TOPEL standard score is reported, but all other results and analyses use the raw scores.

Table 1. Inclusion Criteria

Age 4 or 5 yrs
Enrolled in preschool or kindergarten
No previous glasses wear
Confirmed by cycloplegic refraction as having moderate hyperopia or emmetropia, defined as follows:
➢Hyperopia criteria: ≥3.00 D and ≤6.00 D in the most hyperopic meridian of at least 1 eye with astigmatism ≤1.50 D and anisometropia ≤1.00 D
➢Emmetropia criteria: hyperopia ≤1.00 D, astigmatism, anisometropia, and myopia all <1.00 D
No individualized education program for developmental, educational, or behavioral issues
No strabismus, suspected amblyopia, or ocular disease based on eligibility eye examination
Written informed consent from parent/guardian
No medical or psychologic condition that would interfere with study procedures, including taking ocular or systemic medication known to affect accommodation

D = diopters.

The educational testing assessors were masked with respect to the refractive status of the participating children. Testing was performed without any refractive correction. The parent was asked to wait outside the room during educational testing. If the parent or child was uncomfortable with this arrangement, the parent was allowed to remain in the room during testing but was asked not to interact with the child and was seated outside the child's field of view. A 5- to 10-minute break was given between the second and third sections of the TOPEL. Total test time was approximately 25 minutes.

Statistical Analysis

Determination of TOPEL overall score and subtest scores for each child followed the published scoring guidelines. We compared the TOPEL scores (total and subtest scores) between hyperopes and emmetropes using analysis of variance. The comparison was also performed with the adjustment of covariates affecting TOPEL scores, including chronologic age at the time of the educational assessment, parental education status, and race/ethnicity. The effect of magnitude of hyperopia was assessed by comparing TOPEL scores among children with emmetropia, hyperopia ≥3.0 to <4.0 D, and hyperopia ≥4.0 D (most hyperopic meridian), with the cut point selected on the basis of the findings of Candy et al,[27] that children with more than 4 D of hyperopia (most accurate meridian for accommodation) had more variable accommodative lag. The TOPEL scores were also compared between children with emmetropia and hyperopia on the basis of groups defined by the level of accommodative lag, binocular near VA, and near stereoacuity, with their cut points determined using the limits of the 95% confidence interval of the emmetropes. Specifically, we evaluated performance among hyperopic children using cut points of >1.35 D accommodative lag, 20/40 or worse binocular near VA, and 240 seconds of arc or worse near stereoacuity. We calculated accommodative lag as an average of 5 measurements from the Grand Seiko. We used the procedure of Hochberg and Benjamini[28] to adjust for the multiple comparisons between emmetropes and hyperopes split by normal and low visual function. Multivariable linear regression was used to assess the independent associations of hyperopia and each of the low visual functions with TOPEL scores. All models included chronologic age at the time of the educational assessment, parental education status, race/ethnicity, and an indicator variable for the hyperopic group. A stepwise backward elimination method was applied to the full emmetropic and hyperopic data set, with the indicator variables for hyperopia ≥4.0 D, accommodative lag >1.35 D, binocular near VA 20/40 or worse, and stereoacuity of 240 seconds of arc or worse, applied in the hyperopic group.

Results

A total of 858 children had an eligibility eye examination; 509 were eligible, and 492 children (244 hyperopes and 248 emmetropes) met eligibility criteria and returned for educational assessment. The mean age (±standard deviation) at the time of the early literacy testing was 58.5 (±5.8) months in the hyperopes and 59.2 (±5.5) months in the emmetropes (Table 2). The mean value of the most hyperopic meridian in the more hyperopic eye was +3.78 (±0.81) D in hyperopes and +0.51 (±0.48) D in emmetropes. The majority of children were enrolled in Head Start (89%). There were no significant differences between hyperopes and emmetropes in mean age, sex, parent/caregiver's education level, percentage enrolled in Head Start, race, or ethnicity (Table 2).

The overall mean ± standard deviation TOPEL raw score was 86.6±23.2, and the mean TOPEL standard score was 96.1±13.8. The mean TOPEL total score in hyperopic children was significantly lower than in emmetropic children (−5.9; $P = 0.004$). After adjustment for age, race/ethnicity, and parent/caregiver's education, the mean difference between hyperopes and emmetropes was −4.3 ($P = 0.01$) for TOPEL total score, −2.4 ($P = 0.007$) for Print Knowledge, −1.6 ($P = 0.07$) for Definitional Vocabulary, and −0.3 ($P = 0.39$) for Phonological Awareness (Table 3). In addition, the mean adjusted TOPEL total score in children with ≥4 D of hyperopia was 6.8 points worse than in emmetropes, and the mean Print Knowledge score was 4.0 points worse (Table 4). The differences were not statistically significant between the adjusted mean scores of children with emmetropia versus hyperopia 3 to <4 D or between children with hyperopia 3 to <4 D versus hyperopia ≥4 D, although the adjusted mean score was lower with increasing hyperopia ($P \geq 0.11$) (Table 4).

We also performed analyses to determine whether accommodative response contributed to the associations found between hyperopia and adjusted TOPEL score. Analysis of accommodative response (closest meridian to the target as measured by Grand Seiko autorefraction) revealed that children with the poorest accommodative response (greatest lags) had lower mean scores on the TOPEL, although the differences were not statistically significant ($P \geq 0.05$) (Table 5). The greatest differences in TOPEL score were found between hyperopes with >1.35 D lag and emmetropes for TOPEL total score (−5.7; $P = 0.09$) and for Print Knowledge (−3.4; $P = 0.05$). Results for accommodative response (horizontal meridian) as measured using the Monocular Estimate Method dynamic retinoscopy were not qualitatively different (data not shown).

Analysis to determine whether binocular near VA was predictive of the associations between hyperopia and adjusted TOPEL scores revealed that the mean scores of hyperopes with binocular near VA of 20/40 or worse were significantly worse than those of emmetropic children (−8.5, $P = 0.002$ for total score; −4.5, $P = 0.001$ for Print Knowledge; −3.1, $P = 0.04$ for Definitional Vocabulary) or hyperopic children with binocular near VA better than 20/40 (−6.3, $P = 0.03$ for total score; −3.2, $P = 0.03$ for Print Knowledge). However, the adjusted mean TOPEL scores of hyperopes with good binocular near VA (better than 20/40) were similar to those of emmetropes ($P \geq 0.18$) (Table 6). Analysis of distance VA resulted in the same qualitative conclusions (data not shown).

Table 2. Characteristics of Participating Children by Refractive Error Group

Characteristics	Emmetropic (N = 248)		Hyperopic (3–6 D) (N = 244)		P
Demographic					
Age at TOPEL administration, mos					
48–53	51	(20.6)	65	(26.6)	
54–59	87	(35.1)	81	(33.2)	
60–65	78	(31.5)	70	(28.7)	
66–<72	32	(12.9)	28	(11.5)	
Mean (SD)	59.2	(5.5)	58.5	(5.8)	0.14
Sex					
Male	128	(51.6)	114	(46.7)	
Female	120	(48.4)	130	(53.3)	0.28
Ethnicity and race					
Non-Hispanic black	150	(60.5)	140	(57.4)	
Non-Hispanic white	20	(8.1)	28	(11.5)	
Hispanic	61	(24.6)	63	(25.8)	
Other or unknown	17	(6.9)	13	(5.3)	0.53
Education level of parent or caregiver					
Less than high school	18	(7.3)	27	(11.1)	
High school	92	(37.1)	102	(41.8)	
Some college	55	(22.2)	39	(16.0)	
2-yr college	21	(8.5)	22	(9.0)	
4-yr college	23	(9.3)	23	(9.4)	
Graduate degree	19	(7.7)	12	(4.9)	
Unknown	20	(8.1)	19	(7.8)	0.35
Preschool/kindergarten					
Head Start	224	(90.3)	215	(88.1)	
Other preschool/kindergarten	24	(9.7)	29	(11.9)	0.43
Ocular					
Most hyperopic meridian, more hyperopic eye, D, Mean (SD)	0.51	(0.48)	3.78	(0.81)	—
Spherical equivalent, more hyperopic eye, D, Mean (SD)	0.37	(0.50)	3.47	(0.81)	—

Data are n (%) unless otherwise indicated.
D = diopters; SD = standard deviation; TOPEL = Test of Preschool Early Literacy.

Likewise, an analysis to determine whether near stereoacuity was associated with TOPEL performance showed that the scores of hyperopic children with near stereopsis 240 seconds of arc or worse were significantly worse than those of emmetropic children (−8.6, $P < 0.001$ for total score; −5.3, $P < 0.001$ for Print Knowledge) or hyperopic children with near stereopsis better than 240 seconds of arc (−7.1, $P = 0.009$ for total score; −4.8, $P < 0.001$ for Print Knowledge). The adjusted TOPEL scores of emmetropes and hyperopes with good near stereopsis (better than 240 seconds of arc) were not significantly different ($P \geq 0.38$) (Table 7).

When the factors of hyperopia 3.0 to 6.0 D, hyperopia 4.0 to 6.0 D, accommodative lag >1.35 D, binocular near VA 20/40 or worse, and near stereopsis 240 seconds of arc or worse were all included in a linear regression model, the strongest predictor of lower total TOPEL score and Print Knowledge score was stereopsis 240 seconds of arc or worse (−5.4 points, $P = 0.04$ for total TOPEL; −4.2, $P = 0.002$ for Print Knowledge) (Table 8). Although all of these factors are correlated, when nonsignificant factors were removed from the model through backward elimination, no factors other than poor stereopsis were retained.

Discussion

This study compared performance of an assessment of early literacy (TOPEL) in emmetropic and uncorrected hyperopic (≥3 to ≤6 D) 4- or 5-year-old children without strabismus

Table 3. Test of Preschool Early Literacy Scores by Refractive Error Group

TOPEL Score	Emmetropic (n = 248)		Hyperopic (3–6 D) (n = 244)		Unadjusted		Adjusted*	
	Mean	SD	Mean	SD	Difference (95% CI)	P	Difference (95% CI)	P
Total	89.4	23.5	83.5	22.9	−5.9 (−10.0 to −1.8)	0.004	−4.3 (−7.7 to −0.9)	0.01
Print Knowledge	22.9	10.7	19.7	11.3	−3.1 (−5.1 to −1.2)	0.002	−2.4 (−4.1 to −0.6)	0.007
Definitional Vocabulary	51.2	11.2	48.9	11.1	−2.3 (−4.3 to −0.3)	0.02	−1.6 (−3.4 to 0.3)	0.07
Phonological Awareness	15.4	5.4	14.9	4.8	−0.5 (−1.4 to 0.4)	0.28	−0.3 (−1.1 to 0.4)	0.39

CI = confidence interval; SD = standard deviation; TOPEL = Test of Preschool Early Literacy.
*Adjusted for age at testing in months, race, and ethnicity of participant, and education level of parent or caregiver.

Table 4. Comparison of Mean Adjusted Test of Preschool Early Literacy Scores by Refractive Error (Most Hyperopic Meridian)

Groups	Compared with	Adjusted† Mean Difference (95% CI)							
		Total	*P**	*Print Knowledge*	*P**	*Definitional Vocabulary*	*P**	*Phonological Awareness*	*P**
Emmetropic (N = 248)	Hyperopic, <4 D (N = 159)	−2.9 (−6.8 to 0.09)	0.13	−1.5 (−3.4 to 0.5)	0.14	−1.5 (−3.5 to 0.5)	0.28	−0.0 (−0.9 to 0.9)	0.99
Emmetropic (N = 248)	Hyperopic, ≥4 D (N = 85)	−6.8 (−11.6 to −2.1)	0.01	−4.0 (−6.4 to −1.6)	0.003	−1.9 (−4.3 to 0.5)	0.28	−1.0 (−2.0, 0.1)	0.19
Hyperopic, <4 D (N = 159)	Hyperopic, ≥4 D (N = 85)	−3.9 (−8.9 to 1.2)	0.13	−2.5 (−5.1 to 0.1)	0.11	−0.4 (−3.0 to 2.2)	0.76	−1.0 (−2.1 to 0.2)	0.19

CI = confidence interval; D = diopters.
Hyperopic <4 D = hyperopic 3–<4 D; hyperopic ≥4 D = hyperopic 4–6 D.
**P* values were adjusted using the procedure described by Hochberg and Benjamini.[28]
†Adjusted for age at testing in months, race, and ethnicity of participant, and education level of parent or caregiver.

or amblyopia. We found significantly greater deficits in the TOPEL score in hyperopic children with ≥4.0 D in at least 1 meridian compared with emmetropic children (−6.8, $P = 0.01$ for total score; −4.0, $P = 0.003$ for Print Knowledge). Hyperopic children with <4.0 D also had lower scores than the emmetropic children, but the difference was not statistically significant. It is of interest that the greatest deficits occurred in children with ≥4.0 D hyperopia given the typical working distance for preschoolers of approximately 33 cm (3 D) and the finding that the blur-driven amplitude of accommodation in preschool children is approximately 7 D.[7] The greatest deficits were found for print knowledge, which assesses skills such as print awareness and the ability to identify letters or written words, plus identifying letters associated with particular sounds.[20] Milder deficits in definitional vocabulary were found for children with hyperopia versus children with emmetropia overall and for hyperopes with binocular near VA of 20/40 or worse versus emmetropes. This subtest assesses the ability to name and describe an important attribute of everyday objects.[20] However, hyperopic and emmetropic children had similar performance for phonological awareness, which evaluates the ability to drop and blend specific sounds in everyday words.[20]

Reported deficits in visuocognitive and visuomotor ability in hyperopic children have been attributed to a neural processing deficit in hyperopia.[9] However, preliminary evidence that normalization of deficits may be possible with spectacle correction[17] and the report of reduced reading and academic performance with simulated hyperopia[29] seem to argue against the theory that an irremediable neural deficit underlies the performance differences. Furthermore, the association between hyperopia and deficits in visual but not auditory aspects of early literacy found in this study and the study by Shankar et al[18] argue against this theory.

Hyperopic children with binocular near VA 20/40 or worse or near stereoacuity 240 seconds of arc or worse performed significantly worse on the TOPEL than emmetropic children (Tables 6 and 7). On the other hand, hyperopic children with better binocular near VA (better than 20/40) and near stereoacuity (120 seconds of arc or better) performed similarly to the emmetropic children. When both factors were included in linear regression models, only the association of stereoacuity with total TOPEL and Print Knowledge was statistically significant (Table 8). However, the magnitude of the estimated effect of reduced binocular near VA for total TOPEL was similar to the effect of poor stereoacuity (−4.1 vs. −5.4), and the lower bound of the 95% confidence interval

Table 5. Comparison of Mean Adjusted Test of Preschool Early Literacy Scores by Refractive Error Group and Accommodative Lag (as Measured by Grand Seiko, Closest Meridian)

Groups	Compared with	Adjusted† Mean Difference (95% CI)							
		Total	*P**	*Print Knowledge*	*P**	*Definitional Vocabulary*	*P**	*Phonological Awareness*	*P**
Emmetropic (N = 248)	Hyperopic, ≤1.35 D lag (N = 185)	−3.9 (−7.6 to −0.2)	0.09	−2.0 (−3.9 to −0.2)	0.06	−1.7 (−3.5 to 0.2)	0.25	−0.2 (−1.0 to 0.6)	0.61
Emmetropic (N = 248)	Hyperopic, >1.35 D lag (N = 59)	−5.7 (−11.2 to −0.2)	0.09	−3.4 (−6.2 to −0.6)	0.0504	−1.5 (−4.4 to 1.3)	0.58	−0.7 (−2.0 to 0.5)	0.61
Hyperopic, ≤1.35 D lag (N = 185)	Hyperopic, >1.35 D lag (N = 59)	−1.8 (−7.5 to 3.9)	0.54	−1.4 (−4.3 to 1.5)	0.35	0.1 (−2.8 to 3.1)	0.93	−0.5 (−1.8 to 0.8)	0.61

CI = confidence interval; D = diopters.
**P* values were adjusted using the procedure described by Hochberg and Benjamini.[28]
†Adjusted for age at testing in months, race, and ethnicity of participant, and education level of parent or caregiver.

Table 6. Comparison of Adjusted Mean Test of Preschool Early Literacy Scores by Refractive Error Group and Binocular Near Visual Acuity

Groups	Compared with	Adjusted† Mean Difference (95% CI)							
		Total	*P**	*Print Knowledge*	*P**	*Definitional Vocabulary*	*P**	*Phonological Awareness*	*P**
Emmetropic (N = 248)	Hyperopic, better than 20/40 (N = 159)	−2.2 (−6.0 to 1.5)	0.25	−1.3 (−3.2 to 0.6)	0.18	−0.9 (−2.8 to 1.1)	0.38	−0.0 (−0.9 to 0.8)	0.92
Emmetropic (N = 248)	Hyperopic, 20/40 or worse (N = 85)	−8.5 (−13.3 to −3.7)	0.002	−4.5 (−6.9 to −2.0)	0.001	−3.1 (−5.6 to −0.6)	0.04	−0.9 (−2.0 to 0.2)	0.27
Hyperopic, better than 20/40 (N = 159)	Hyperopic, 20/40 or worse (N = 85)	−6.3 (−11.4 to −1.2)	0.03	−3.2 (−5.7 to −0.6)	0.03	−2.2 (−4.9 to 0.4)	0.19	−0.9 (−2.0 to 0.3)	0.27

CI = confidence interval.
*P values were adjusted using the procedure described by Hochberg and Benjamini.[28]
†Adjusted for age at testing in months, race, and ethnicity of participant, and education level of parent or caregiver.

was −9.6. Near stereoacuity is a measure of binocular visual function that is reduced in the presence of many visual disorders, including reduced VA and inaccurate focus.[30,31]

Hyperopic children with the poorest accommodative response (greatest accommodative lag) scored lower on the total TOPEL and Print Knowledge than emmetropic children, but not to a statistically significant degree (Table 5). However, accommodative response as measured by the Grand Seiko was not as closely associated with performance on the test of literacy as binocular near VA or near stereoacuity. It may be that the in-instrument testing with the Grand Seiko resulted in better accommodative performance than that generally achieved in normal viewing conditions or with print. In addition, accommodative response measured during the brief testing procedure may not reflect the ability to sustain focus.

The VIP-HIP was designed with sufficient statistical power for the primary comparison of children with emmetropia with children with hyperopia of 3.0 to 6.0 D. In addition to examining TOPEL scores within 2 subgroups on the basis of degree of hyperopia, we explored the TOPEL scores in subgroups on the basis of 3 correlated visual functions: accommodative lag, binocular near VA, and near stereoacuity. The sample sizes in these subgroups are not sufficient to provide high statistical power for detecting differences, especially in multivariable analyses. Therefore, failure to achieve statistically significant differences for near VA or accommodative response should not be interpreted as definitive evidence that there is no association between the factor and the TOPEL scores.

Given that the stimuli in the TOPEL test are approximately 20/400 and high contrast, the association between binocular near VA and TOPEL score cannot be due to difficulty seeing the TOPEL test items, but rather is likely due to difficulties with sustained focus and acquisition of early literacy skills. Although children's books generally have large print size (e.g., 20/100), it may be that the VA obtained during brief binocular near VA testing cannot be easily sustained while looking at books, which may result in deficits in early literacy. Intermittent blur may result in difficulty learning letters and inconsistent associations between letters and their corresponding sounds, which may in turn hinder the learning of accurate associations between sounds and letters. Therefore, the association between reading and binocular near VA may be due to the effect of blur on reading; 3 D or more of dioptric blur has been shown to affect reading.[32] Some have speculated that this level of blur may result in distortions and confusions in letters.[32]

Table 7. Comparison of Mean Test of Preschool Early Literacy Scores by Refractive Error Group and Near Stereoacuity

Groups	Compared with	Adjusted† Mean Difference (95% CI)							
		Total	*P**	*Print Knowledge*	*P**	*Definitional Vocabulary*	*P**	*Phonological Awareness*	*P**
Emmetropic (N = 248)	Hyperopic, 120 arcsec or better (N = 145)	−1.5 (−5.4 to 2.3)	0.44	−0.4 (−2.4 to 1.5)	0.66	−1.2 (−3.2 to 0.8)	0.44	0.1 (−0.8 to 1.0)	0.78
Emmetropic (N = 248)	Hyperopic, 240 arcsec or worse (N = 98)	−8.5 (−13.0 to −4.1)	<0.001	−5.3 (−7.5 to −3.0)	<0.001	−2.2 (−4.5 to 0.1)	0.18	−1.0 (−2.0 to −0.0)	0.09
Hyperopic, 120 arcsec or better (N = 145)	Hyperopic, 240 arcsec or worse (N = 98)	−7.0 (−11.8 to −2.1)	0.01	−4.8 (−7.3 to −2.4)	<0.001	−1.0 (−3.5 to 1.5)	0.44	−1.2 (−2.2 to −0.1)	0.09

arcsec = seconds of arc; CI = confidence interval.
*P values were adjusted using the procedure described by Hochberg and Benjamini.[28]
†Adjusted for age at testing in months, race, and ethnicity of participant, and education level of parent or caregiver.

Table 8. Estimated Change in Test of Preschool Early Literacy Scores Relative to Emmetropic Children for Ocular Characteristics from the Multivariable Linear Regression Model*

Test	Characteristic	Estimate	95% CI	P
TOPEL total	Hyperopic group	−0.1	(−4.4 to 4.2)	0.97
	Within the hyperopic group			
	Hyperopia (4–6 D)	−1.5	(−6.9 to 3.9)	0.58
	Accommodative lag >1.35 D	−0.7	(−6.6 to 5.1)	0.80
	Near VA 20/40 or worse	−4.1	(−9.6 to 1.3)	0.13
	Stereoacuity 240 arcsec or worse	−5.4	(−10.6 to −0.3)	0.04
Print Knowledge	Hyperopic group	0.3	(−1.8 to 2.5)	0.76
	Within the hyperopic group			
	Hyperopia (4–6 D)	−1.0	(−3.7 to 1.7)	0.47
	Accommodative lag >1.35 D	−0.8	(−3.8 to 2.1)	0.59
	Near VA 20/40 or worse	−1.5	(−4.3 to 1.2)	0.27
	Stereoacuity 240 arcsec or worse	−4.2	(−6.8 to −1.6)	0.002
Definitional Vocabulary	Hyperopic group	−0.9	(−3.1 to 1.4)	0.45
	Within the hyperopic group			
	Hyperopia (4–6 D)	0.1	(−2.7 to 2.9)	0.95
	Accommodative lag >1.35 D	0.3	(−2.7 to 3.4)	0.82
	Near VA 20/40 or worse	−2.2	(−5.0 to 0.6)	0.13
	Stereoacuity 240 arcsec or worse	−0.4	(−3.1 to 2.3)	0.77
Phonological Awareness	Hyperopic group	0.4	(−0.5 to 1.4)	0.37
	Within the hyperopic group			
	Hyperopia (4–6 D)	−0.6	(−1.8 to 0.6)	0.33
	Accommodative lag >1.35 D	−0.3	(−1.6 to 1.0)	0.68
	Near VA 20/40 or worse	−0.4	(−1.7 to 0.8)	0.48
	Stereoacuity 240 arcsec or worse	−0.9	(−2.1 to 0.3)	0.14

arcsec = seconds of arc; CI = confidence interval; D = diopters; TOPEL = Test of Preschool Early Literacy; VA = visual acuity.
*Adjusted for age at testing in months, race, and ethnicity of participant, and education level of parent or caregiver.

Other investigators have reported that the print size of the reading material should be double the reading acuity to allow comfortable reading.[33] Furthermore, any asthenopia associated with moderate hyperopia may cause young children to read less. It is unknown why some children are able to maintain good visual function in the presence of moderate hyperopia while others are not; these results support prior findings that children with hyperopia 4 D are more likely to have reduced visual function.[34]

Although methodological differences such as age of subjects, tests used, and definition of hyperopia prevent direct comparison, these results support previous findings of an association between hyperopia and reduced reading ability in preschool[18] and school-aged children.[4–7,13–17] Simons and Gassler[4] performed a meta-analysis of 34 studies and concluded that hyperopia in school children was associated with below-average reading ability because of the required extra accommodative effort producing eyestrain, intermittent blurring of letters, headaches, and fatigue. Rosner and Rosner[16] concluded that uncorrected hyperopia of >1.25 D was associated with decreased educational achievement. Furthermore, the results support the theory that the extra accommodative effort or inefficient visual function may make learning and reading more difficult.[4–6] Stewart-Brown et al[5] reported that among a British cohort of 12 853 10-year-old children, children with normal distance VA but decreased near VA (most commonly caused by mild or moderate uncorrected hyperopia) scored worse than children with normal distance and near VA on standardized reading tests (but not mathematics tests), even after adjustment for differences in intelligence, sex, and social class. A high percentage of Head Start children were enrolled in the current study, and it is possible that these children may differ from children from a higher socioeconomic group. However, comparisons were performed with adjustment for covariates affecting TOPEL scores, including age, parental education status, and race/ethnicity.

Our results show that some uncorrected hyperopic children have deficits in early literacy and essential skills shown to be associated with future problems learning to read and write. Effect size provides a measure of the magnitude of the difference between groups. For children with ≥4.0 D of hyperopia (most hyperopic meridian) compared with emmetropic children, the deficits in TOPEL score represent an effect size of 0.30 for total TOPEL score, 0.36 for Print Knowledge, 0.17 for Definitional Vocabulary, and 0.19 for Phonological Awareness. These differences are meaningful and of a magnitude that is generally addressed with intervention in educational settings to allow future academic success. The "What Works Clearinghouse" criteria describe an effect size of ≥+0.25 as "substantively important."[35] Our findings are noteworthy because early deficits in reading performance have been shown to be predictive of future reading performance.[36] In fact, children with reading difficulty at the end of first grade have been shown to have an 88% chance of remaining poor readers at the end of fourth grade.[37] These early differences are meaningful to later reading success given that early reading ability also has been found to be predictive of high school

performance.[38] Given the significance of the development of these early skills, it is important to note that early reading failure often could be prevented by decreasing the frequency of deficits in vocabulary, phonological awareness, and print knowledge upon entry to kindergarten or first grade.[36] Although our results implicate deficits in near stereoacuity and to a lesser degree reduced binocular near VA, the presence of hyperopia ≥4.0 D, reduced near stereoacuity, and reduced binocular near VA are all strongly correlated. Furthermore, the current results are only relevant to children with moderate hyperopia (3.0−6.0 D). However, these results do suggest that referral for assessment of early literacy skills should be considered in children with ≥4.0 D of hyperopia and children with hyperopia (3.0−6.0 D) accompanied by deficits in binocular near VA or near stereoacuity. Reported benefits of educational intervention to address deficits in early literacy include fewer referrals for special education services, reduced grade retention rates, increased graduation rates, and less juvenile delinquency.[39]

Further research is needed to determine the effect of refractive correction on these educational deficits. It is important to determine whether correction of hyperopia may benefit preschool children by improving their ability to perform visually and academically.

References

1. Giordano L, Friedman DS, Repka MX, et al. Prevalence of refractive error among preschool children in an urban population: the Baltimore Pediatric Eye Disease Study. Ophthalmology 2009;116:739–46. 46 e1−4.
2. Multi-Ethnic Pediatric Eye Disease Study Group. Prevalence of myopia and hyperopia in 6- to 72-month-old African American and Hispanic children: the Multi-Ethnic Pediatric Eye Disease Study. Ophthalmology 2010;117:140–147.e3.
3. Arnold RW. Pseudo-false positive eye/vision photoscreening due to accommodative insufficiency. A serendipitous benefit for poor readers? Binocul Vis Strabismus Q 2004;19:75–80.
4. Simons HD, Gassler PA. Vision anomalies and reading skill: a meta-analysis of the literature. Am J Optom Physiol Opt 1988;65:893–904.
5. Stewart-Brown S, Haslum MN, Butler N. Educational attainment of 10-year-old children with treated and untreated visual defects. Dev Med Child Neurol 1985;27:504–13.
6. Grisham JD, Simons HD. Refractive error and the reading process: a literature analysis. J Am Optom Assoc 1986;57:44–55.
7. Anderson HA, Hentz G, Glasser A, et al. Minus-lens-stimulated accommodative amplitude decreases sigmoidally with age: a study of objectively measured accommodative amplitudes from age 3. Invest Ophthalmol Vis Sci 2008;49:2919–26.
8. Anderson HA, Glasser A, Stuebing KK, Manny RE. Minus lens stimulated accommodative lag as a function of age. Optom Vis Sci 2009;86:685–94.
9. Atkinson J, Anker S, Nardini M, et al. Infant vision screening predicts failures on motor and cognitive tests up to school age. Strabismus 2002;10:187–98.
10. Simons K. Hyperopia, accommodative dysfunction and reading. Binocul Vis Strabismus Q 2004;19:69–70.
11. Williams WR, Latif AH, Hannington L, Watkins DR. Hyperopia and educational attainment in a primary school cohort. Arch Dis Child 2005;90:150–3.
12. Quaid P, Simpson T. Association between reading speed, cycloplegic refractive error, and oculomotor function in reading disabled children versus controls. Graefes Arch Clin Exp Ophthalmol 2013;251:169–87.
13. Eames TH. Comparison of eye conditions among 1,000 reading failures, 500 ophthalmic patients, and 150 unselected children. Am J Ophthalmol 1948;31:713–7.
14. Eames TH. The influence of hypermetropia and myopia on reading achievement. Am J Ophthalmol 1955;39:375–7.
15. Rosner J, Rosner J. Comparison of visual characteristics in children with and without learning difficulties. Am J Optom Physiol Opt 1987;64:531–3.
16. Rosner J, Rosner J. The relationship between moderate hyperopia and academic achievement: how much plus is enough? J Am Optom Assoc 1997;68:648–50.
17. Roch-Levecq AC, Brody BL, Thomas RG, Brown SI. Ametropia, preschoolers' cognitive abilities, and effects of spectacle correction. Arch Ophthalmol 2008;126:252–8.
18. Shankar S, Evans MA, Bobier WR. Hyperopia and emergent literacy of young children: pilot study. Optom Vis Sci 2007;84:1031–8.
19. Helveston EM, Weber JC, Miller K, et al. Visual function and academic performance. Am J Ophthalmol 1985;99:346–55.
20. Lonigan C, Wagner R, Torgesen J, Rashotte C. Test of Preschool Early Literacy Examiner's Manual. Austin, TX: Pro-Ed; 2007.
21. National Association for the Education of Young Children and the National Association of Early Childhood Specialists in State Departments of Education. Early Childhood Curriculum, Assessment, and Program Evaluation: Building an Effective, Accountable System in Programs for Children Birth Through Age 8: Joint Position Statement. Washington, DC: National Association for the Education of Young Children and the National Association of Early Childhood Specialists in State Departments of Education; 2005.
22. National Early Literacy Panel. Report on a Synthesis of Early Predictors of Reading. Louisville, KY: National Center for Family Literacy; 2006.
23. Vision In Preschoolers Study Group. Sensitivity of screening tests for detecting vision in preschoolers-targeted vision disorders when specificity is 94%. Optom Vis Sci 2005;82:432–8.
24. Moke PS, Turpin AH, Beck RW, et al. Computerized method of visual acuity testing: adaptation of the amblyopia treatment study visual acuity testing protocol. Am J Ophthalmol 2001;132:903–9.
25. Pediatric Eye Disease Investigator Group. A randomized trial of atropine regimens for treatment of moderate amblyopia in children. Ophthalmology 2004;111:2076–85.
26. Ciner EB, Ying G-S, Kulp MT, et al; Vision In Preschoolers Study Group. Stereoacuity of preschool children with and without vision disorders. Optom Vis Sci 2014;91:351–8.
27. Candy TR, Gray KH, Hohenbary CC, Lyon DW. The accommodative lag of the young hyperopic patient. Invest Ophthalmol Vis Sci 2012;53:143–9.
28. Hochberg Y, Benjamini Y. More powerful procedures for multiple significance testing. Stat Med 1990;9:811–8.
29. Narayanasamy S, Vincent SJ, Sampson GP, Wood JM. Impact of simulated hyperopia on academic-related performance in children. Optom Vis Sci 2015;92:227–36.
30. Wood IC. Stereopsis with spatially-degraded images. Ophthalmic Physiol Opt 1983;3:337–40.
31. Schmidt PP. Sensitivity of random dot stereoacuity and Snellen acuity to optical blur. Optom Vis Sci 1994;71:466–71.
32. Chung ST, Jarvis SH, Cheung SH. The effect of dioptric blur on reading performance. Vision Res 2007;47:1584–94.

33. Whittaker SG, Lovie-Kitchin J. Visual requirements for reading. Optom Vis Sci 1993;70:54–65.
34. Babinsky E, Candy TR. Why do only some hyperopes become strabismic? Invest Ophthalmol Vis Sci 2013;54:4941–55.
35. What Works Clearinghouse. What Works Clearinghouse Procedure and Standards Handbook. Washington, DC: Institute of Education Sciences; 2013.
36. Snow CE, Burns MS, Griffin PE. Preventing Reading Difficulties in Young Children. Washington, DC: National Academy Press; 1998.
37. Juel C. Learning to read and write - a longitudinal-study of 54 children from 1st through 4th grades. J Educ Psychol 1988;80:437–47.
38. Cunningham A, Stanovich H. Early reading acquisition and its relation to reading experience and ability 10 years later. Dev Psychol 2003;33:934–45.
39. Reynolds AJ, Temple JA, Ou SR. School-based early intervention and child well-being in the Chicago Longitudinal Study. Child Welfare 2003;82:633–56.

Footnotes and Financial Disclosures

Originally received: July 11, 2015.
Final revision: November 12, 2015.
Accepted: November 20, 2015.
Available online: January 26, 2016. Manuscript no. 2015-1165.

[1] The Ohio State University, College of Optometry, Columbus, Ohio.

[2] Pennsylvania College of Optometry at Salus University, Elkins Park, Pennsylvania.

[3] Department of Ophthalmology, University of Pennsylvania, Philadelphia, Pennsylvania.

[4] New England College of Optometry, Boston, Massachusetts.

[5] American Institutes for Research, Washington, DC.

[6] Northeastern State University College of Optometry, Tahlequah, Oklahoma.

[7] Indiana University School of Optometry, Bloomington, Indiana.

[8] Division of Ophthalmology, Children's Hospital of Philadelphia, University of Pennsylvania, Philadelphia, Pennsylvania.

Presented in part at: the Association for Research in Vision and Ophthalmology Meeting, May 6, 2015, Fort Lauderdale, Florida.

A list of participating members of the VIP-HIP Study Group :(C = Coordinator; EA = Educational Assessor; EE = Eye Examiner; PI = Principal Investigator)*:

Pennsylvania College of Optometry at Salus University: Elise Ciner, OD (PI, EE); Whitley Harbison (C, EA); Zack Margolies, MSW (EA); Sarah McHugh-Grant (C, EA); Erin Engle (EA); Richard Schulang, MEd (EA); Gale Orlansky, OD, MEd (EE); Leah Sack (C); Jasmine Campbell (C).

The Ohio State University College of Optometry: Marjean Taylor Kulp, OD, MS (PI); Julie Preston, OD, PhD, MEd (EA); Andrew Toole, OD, PhD (EE); Tamara Oechslin, OD, MS (EE); Nancy Stevens, MS, RD, LD (C); Pam Wessel (C).

New England College of Optometry: Bruce Moore, OD (PI); Marcia Feist-Moore, MEd (EA); Catherine Johnson, OD (EE); Stacy Lyons, OD (EE); Nicole Quinn, OD (EE); Renee Mills, BS (C).

Data Coordinating Center at University of Pennsylvania: Maureen Maguire, PhD (PI); Maria Blanco; Mary Brightwell-Arnold; James Dattilo; Sandra Harkins; Christopher Helker, MSPH; Ellen Peskin, MA; Maxwell Pistilli, MS; Gui-Shuang Ying, PhD.

VIP-HIP Executive Committee: Marjean Taylor Kulp, OD, MS (Study Chair); Elise Ciner, OD; Maureen Maguire, PhD; Bruce Moore, OD; Lynn Cyert, OD, PhD; Graham Quinn, MD, MSCE; Rowan Candy, PhD; Jill Pentimonti, PhD, Gui-Shuang Ying, PhD, Educational Consultants: Robert H. Bradley, PhD, Laura Justice, PhD, CCC-SLP, Jill Pentimonti, PhD Velma Dobson, PhD contributed to the design of the study, NEI Liaison: Maryann Redford, DDS, MPH.

*Individuals dually certified as a Coordinator and an Educational Assessor did not perform both roles for any one child.

Financial Disclosure(s):
The author(s) have made the following disclosure(s): E.C.: Grants and nonfinancial support – National Institutes of Health/National Eye Institute during the conduct of the study, and Salus University receives royalties from Vision Assessment Corporation for the PASS Test used in this study.

M.T.K., M.M., M.P., and T.R.C.: Grants – National Institutes of Health during the conduct of the study.

G-s.Y.: Grants – National Eye Institute; Personal fees – Janssen R&D, outside the submitted work.

Supported by the National Eye Institute of the National Institutes of Health, Department of Health and Human Services (R01EY021141). The funding organization had no role in the design or conduct of this research.

Author Contributions:

Conception and design: Kulp, Ciner, Maguire, Moore, Cyert, Candy, Quinn, Ying

Data collection: Kulp, Ciner, Maguire, Moore

Analysis and interpretation: Kulp, Ciner, Maguire, Moore, Pentimonti, Pistilli, Cyert, Candy, Quinn, Ying

Obtained funding: Kulp, Ciner, Maguire, Moore, Cyert, Quinn, Ying

Overall responsibility: Kulp, Ciner, Maguire, Moore, Pentimonti, Pistilli, Cyert, Candy, Quinn, Ying

Abbreviations and Acronyms:
D = diopters; **TOPEL** = Test of Preschool Early Literacy; **VA** = visual acuity; **VIP-HIP** = Vision In Preschoolers - Hyperopia in Preschoolers.

Correspondence:
Marjean Taylor Kulp, OD, MS, The OSU College of Optometry, 338 West 10th Avenue, Columbus, OH 43210. E-mail: Kulp.6@osu.edu.