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Visual Function of Moderately Hyperopic 4- and 5-Year-Old Children in the Vision In Preschoolers - Hyperopia In Preschoolers Study

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Abstract

Purpose—To compare visual performance between emmetropic and uncorrected moderately hyperopic preschool age children without strabismus or amblyopia.

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Design—Cross-sectional study.

Methods

Setting: Multicenter, institutional.

Patient or Study Population: Children aged 4 or 5 years.

Intervention or Observation Procedures: Visual functions were classified as normal or reduced for each child based on the 95% confidence interval for emmetropes. Hyperopic (≥ 3.0 diopters [D] to ≥ 6.0 D in the most hyperopic meridian; astigmatism ≥ 1.50 D; anisometropia ≥ 1.0 D) and emmetropic status were determined by cycloplegic autorefraction.

Main Outcome Measures: Uncorrected monocular distance and binocular near visual acuity (VA); accommodative response; and near random dot stereoacuity.

Results—Mean ($\pm$ SD) LogMAR distance VA among 248 emmetropes was better than among 244 hyperopes for the better (0.05 ± 0.10 vs. 0.14 ± 0.11 , $p < .001$) and worse eyes (0.10 ± 0.11 vs. 0.19 ± 0.10 , $p < .001$). Mean binocular LogMAR near VA was better in emmetropes than hyperopes (0.13 ± 0.11 vs. 0.21 ± 0.11 , $p < .001$). Mean accommodative response for emmetropes was lower than for hyperopes for both Monocular Estimation Method (1.03 ± 0.51 D vs. 2.03 ± 1.03 D, $p < .0001$) and Grand Seiko (0.46 ± 0.45 D vs. 0.99 ± 1.0 D, $p < .0001$). Median near stereoacuity was better in emmetropes than hyperopes (40 sec arc vs. 120 sec arc, $p < .0001$). The average number of reduced visual functions was lower in emmetropic than in hyperopic children (.19 vs. 1.0 $p < .0001$).

Conclusions—VA, accommodative response, and stereoacuity were significantly reduced in moderate uncorrected hyperopic preschool children compared to emmetropes. Higher hyperopes (≥ 4 to ≥ 6 D) were at greatest risk, although more than half of children with lower magnitudes (≥ 3 to < 4 D) demonstrated one or more reductions in function.

Introduction

Hyperopia is the most frequently occurring refractive error in young children with a prevalence in preschool children of up to 12% for $\geq +3.00$ diopters (D) depending on the population and definition of hyperopia used.^{1–4} Based upon population estimates from the U.S. Census Bureau and the prevalence of moderate hyperopia, an estimated 550,000 to 1.7 million preschool children each year are expected to have hyperopia of at least $\geq +3.00$ D in the U.S.⁵

The association between moderate hyperopia and the presence of ocular conditions, such as amblyopia or strabismus has been documented previously for young children.^{6–14} The additional accommodative effort associated with uncorrected hyperopia and the resultant accommodative convergence places these children at an increased risk for esotropia, with the risk increasing with the magnitude of hyperopia.^{9,14–20} Hyperopic children are also at an increased risk for development of unilateral or bilateral amblyopia or reduced visual acuity (VA) that is dependent on the magnitude of the hyperopia.^{9,14–17,21–24} Even in the absence of esotropia or amblyopia, preschool children with greater than 3.25 D of uncorrected hyperopia have been shown to have an increased risk for other vision disorders including anisometropia, astigmatism and reduced stereoacuity, the latter worsening with higher

magnitudes of hyperopia.⁹ Children with moderate to high amounts of uncorrected hyperopia may show differences in accommodative convergence to accommodation (AC/A) ratios.^{25–27} This represents less accurate accommodative responses (increased lag of accommodation) and an increase in variability of accommodative effort to maintain clarity for distance and near viewing compared to children with lower magnitudes of hyperopia or emmetropia.²⁷

The Vision in Preschoolers-Hyperopia in Preschoolers Study Group compared early literacy in non-strabismic, non-amblyopic, four and five-year-old children with emmetropia (hyperopia $\leq 1.0\text{D}$, anisometropia, astigmatism, and myopia all $<1.0\text{D}$) versus moderate hyperopia (3.0D to 6.0D in the most hyperopic meridian of at least one eye, with astigmatism $\leq 1.5\text{D}$ and anisometropia $\leq 1.0\text{D}$) and found that children with hyperopia 4.0D alone or hyperopia 3.0D to 6.0D associated with reduced near VA (20/40 or worse) or reduced stereoacuity (240 sec arc or worse) performed worse on a test of early literacy as compared to emmetropic children who demonstrated average performance. On the other hand, children with moderate hyperopia, good near VA and stereoacuity performed similarly to emmetropic children.²⁸ The purpose of the present analysis provides important new insights into associations between moderate uncorrected hyperopia and near visual function in the absence of amblyopia or strabismus. It also shows the effect of increasing hyperopia by comparing these visual functions (distance VA, binocular near VA, accommodative response and near stereoacuity) in this large population of moderately hyperopic and emmetropic, non-strabismic and non-amblyopic four- and five-year-old children enrolled in the VIP-HIP Study.

Methods

This is a secondary data analysis of the multicenter, prospective, cross-sectional VIP-HIP study data collected over a three-year period (2011 to 2014) on uncorrected moderately hyperopic and emmetropic children without strabismus or amblyopia. The VIP-HIP Study adhered to the tenets of the Declaration of Helsinki and was approved prospectively by the appropriate local Institutional Review Boards associated with each study site. Prior to participation, parents or legal guardians of participating children provided written informed consent. This study was conducted in accordance with HIPAA regulations.

Subjects

Children attending preschool or kindergarten identified as potentially having emmetropia or moderate hyperopia through a school vision screening were invited to participate in the VIP-HIP Study. All children were 4 or 5 years of age at the time of enrollment and eligibility eye examination. Children with an Individualized Education Program for developmental, educational, or behavioral issues, those with a known history of strabismus or amblyopia, or children who previously wore correction for refractive error were excluded.

Eligibility Criteria

Children were included in the analysis if they were found to have either hyperopia (defined as 3.0D to 6.0D in the most hyperopic meridian of at least one eye, with astigmatism

1.5D and anisometropia $\geq 1.0D$) or emmetropia (defined as hyperopia $\leq 1.0D$, and astigmatism, anisometropia and myopia each $<1.0D$) on cycloplegic autorefraction. Children with strabismus or suspected amblyopia (VA worse than 20/40 or two or more lines worse than the contralateral eye) were excluded from this analysis and did not participate in the early literacy assessments that were the primary aim of the VIP-HIP Study.

Eye Examinations

Eligibility eye examinations were performed at three participating clinical centers (Pennsylvania College of Optometry at Salus University, Philadelphia, PA; The Ohio State University College of Optometry, Columbus, Ohio, or New England College of Optometry, Boston, MA) or in specially equipped Vision in Preschooler vans²⁹ parked at the child's school. The vans provided an environment similar to the examination rooms at the clinical centers and allowed greater access to participation for families who were unable to bring their child to a clinical center. The eye examination procedures were delineated in a Manual of Procedures and were performed by study-certified licensed eye care professionals experienced in working with young children. The order of testing was distance VA, binocular near VA, accommodative response, near stereoacuity, ocular alignment, cycloplegic refraction, ocular health. Refraction was performed at the end of the eye examination so the child's refractive status was unknown at the time of VA, accommodative and stereoacuity testing.

Distance VA Assessment

Distance VA thresholds were determined monocularly, with computerized crowded HOTV testing using the ATS protocol^{30,31}. Children were asked to point to each letter on a matching lap card. Children with reduced VA on initial testing were retested with full correction after cycloplegia to rule out amblyopia. All other testing was performed without correction.

Binocular Near VA Assessment

Near VA was tested binocularly at 40 cm with crowded HOTV letters, using a modified ATS4 protocol,^{32,33} in order to obtain a measure of the child's clarity of near vision under habitual conditions when performing near work. Children pointed to the letters with a double edged Q-tip 'pointer' that helped maintain their working distance, increased their interest in the task and kept the cards free of fingerprints and smudges.

Accommodative Response

Accommodative response (target at 33 cm) was measured while the child viewed high-interest, colorful targets (a detailed sticker of popular cartoon characters) using Monocular Estimation Method (MEM) dynamic retinoscopy (two readings of the horizontal meridian of the right eye) and Grand Seiko open field autorefraction (five readings of the right eye). The examiner asked the child to describe what was on the sticker and asked questions about the characters to keep the child engaged during each task.

Near Stereoacuity

Assessment of sensory stereopsis at near was performed with the Preschool Assessment of Stereopsis with a Smile (PASS), a two alternative forced choice random dot stereopsis test (blank, demonstration, 480, 240, 120, 60, 40 and 30 sec arc test cards).^{34–35} While wearing colorful pediatric size polarized glasses, children viewed a demonstration card with no disparity ‘Card A’ that was initially presented paired next to a blank card (random dot pattern only) to ascertain testability. This was followed by paired presentations of the blank and a test card with a random dot smile face target beginning with Card B (480 sec arc) and continuing to Card G (30 sec arc). Children were required to pass 4 of 4 or 4 of 5 trials at each level. The order of testing was streamlined, to reduce fatigue and the number of trials required, by skipping the 240 and 40 sec arc cards (Cards C and F) unless the subsequent card was missed.

Ocular alignment

Cover testing at near was performed using fixation sticks with small, colorful, age-appropriate, high interest accommodative targets. The targets were periodically changed to maintain the child’s interest in the task. Cover testing at a 10-foot distance was performed while the child looked at a small colorful character on a monitor. Magnitude of any phoria was neutralized with a prism bar or loose prism.

Refractive Error

Following completion of binocular near VA, accommodative response, near stereoacuity and ocular alignment testing, 1% cyclopentolate was administered and cycloplegic refraction was measured with the Retinomax after 30 to 45 minutes.

Ocular Health

Assessments of pupils, anterior and posterior ocular health were performed to rule out the presence of ocular abnormalities or disease.

Statistical Analysis

Distributions of demographic characteristics and the results of visual function testing were compared between refractive error groups using Fisher’s exact test for categorical variables and analysis of variance for continuous variables. Calculations for VA scores were performed using the LogMAR (logarithm of the minimum angle of resolution) transformation; similarly, calculations of stereoacuity were performed using a logarithmic transformation of the seconds of arc. Near stereoacuity results of “Unable” for children who could not complete the demonstration card were considered missing. A score of 1600 seconds of arc was assigned when children could complete only the demonstration card. The closest meridian to the target was used in the analysis of accommodative response by Grand Seiko, which was selected for assessment of accommodative response because Grand Seiko has been shown to be an effective and objective measure of accommodative response in previous clinical trials such as The Collaborative Longitudinal Evaluation of Ethnicity and Refractive Error (CLEERE) and Correction of Myopia Evaluation Trial 2 (COMET2).^{36–38} Visual functions were considered reduced if they were worse than the limit of the 95%

confidence interval in the emmetropes; specifically, accommodative lag $>1.35D$, binocular near VA 20/40 or worse and near stereoacuity 240 sec arc or worse. Two-sided p -value <0.05 is considered to be statistically significant.

Results

Eight hundred and fifty-eight children were examined and a total of 492 children (mean age = 58 months) were confirmed to have either emmetropia ($n=248$) or hyperopia ($n=244$) in the absence of amblyopia or strabismus. The majority of children were enrolled in Head Start ($n=439$; 89%). There were no significant differences between the hyperopes and emmetropes in mean age, sex, race, ethnicity, parent or guardian educational level or percent enrolled in Head Start (Table 1). The mean ($\pm$ SD) cycloplegic refraction of the most hyperopic meridian was $+3.78D$ (± 0.81) for the hyperopic children and $+0.51D$ (± 0.48) for the emmetropic children.

Testability

All children were able to complete testing on each of the visual functions assessed except for one child with hyperopia who was unable to complete testing on the PASS.

Differences in Visual Function between Hyperopes and Emmetropes

Differences in visual function (VA, accommodative response and stereoacuity) are shown in Table 2 and described as follows:

Monocular Distance and Binocular Near VA—*Mean* ($\pm$ SD) logMAR uncorrected distance VA was significantly better for emmetropes than for hyperopes for both the better eye (0.05 ± 0.10 vs. 0.14 ± 0.11 , $p<0.001$) and the worse eye (0.10 ± 0.11 vs. 0.19 ± 0.10 , $p<0.001$). More emmetropes than hyperopes were able to achieve a VA of at least 20/20 in both the better seeing eye (133 [54%] vs. 53[22%], $p<0.001$) and the worse seeing eye (85[34%] vs. 21[9%], $p<0.001$). The mean ($\pm$ SD) logMAR binocular near VA of emmetropes was also significantly better than for hyperopes (0.13 ± 0.11 vs. 0.21 ± 0.11 , $p<0.001$). Binocular near VA of 20/25 or better was attained by 154(62%) of emmetropic children and 82(33%) of hyperopic children ($p<0.001$).

Accommodative Response—The mean ($\pm$ SD) accommodative response for a 33cm viewing distance and a naturalistic cartoon image was significantly more accurate (closer to the $+3.00D$ optical demand for the 33 cm viewing distance) in emmetropes than in hyperopes. The difference or ‘lag’ between the optical demand ($+3.00D$) and the actual accommodative response was significantly different between emmetropes and hyperopes for both MEM ($1.03D\pm 0.51$ vs. $2.03D\pm 1.03$ lag on average, $p<0.001$) and for Grand Seiko ($0.46D\pm 0.45$ vs. $0.99D\pm 1.00$ lag on average, $p<0.001$). In addition to a larger lag, there was greater variability in lag across hyperopic children (as indicated by a twice larger SD in hyperopic children than emmetropic children) on both MEM and Grand Seiko ($p<0.001$).

Near Stereoacuity—Median [interquartile range] stereoacuity was better in emmetropes than hyperopes (40 [40, 120] sec arc vs. 120 [60, 240] sec arc, $p<0.001$). More emmetropes

than hyperopes (147[59%] vs. 40[17%], $p<0.001$) attained one of the two best tested levels of stereoacuity (30 or 40 sec arc) whereas more hyperopes than emmetropes (99[40%] vs. 13[5%], $p<0.001$) had 240 sec arc or worse stereoacuity

Reduced near visual function—The mean number of reduced visual functions was higher in hyperopes than emmetropes (1.00 vs 0.19, $p<0.001$) with more hyperopes having one or more reduced near visual functions compared to emmetropes, (157[64%] vs.42[17%], $p<0.001$, Table 3).

Effect of increasing magnitude of hyperopia—Within the hyperopic group (3.0 to 6.0D), as the magnitude of the refractive error increased, the mean number of reduced visual functions more than doubled from 0.67 (for 3.0 to 3.25D) to 1.41 (for 4.0 to 6.0D) ($p<0.001$) and the children with one or more reduced visual functions also increased from 50 of 102(49%) (for 3.0 to 3.25 D) to 37 of 57(65%) (for +3.5 to +3.75D) to 70 of 85(82%) (for +4.0 to +6.0D) ($p<0.001$).(Table 3)

Decreasing visual function was also found on average with increasing hyperopia (3.0 to <4.0D vs. 4.0 to 6.0D) as shown in Table 4. Differences in the means for the three VA measures were approximately 0.05 LogMAR (about a half line on Snellen) worse for children with 4.0 to 6.0D hyperopia versus those with hyperopia of 3.0 to <4.0D (all $p<0.01$). Similarly, accommodative lag was on average 0.45D greater by Grand Seiko and 0.86D greater using MEM dynamic retinoscopy ($p<0.001$ for both comparisons). The median near stereoacuity of the children with 4.0D hyperopia was one card worse than that of children with 3.0 to <4.0D hyperopia (240 vs. 120 arc sec; $p<0.001$).

Association between visual functions—Table 5 displays the distribution of all possible combinations of the three reduced near visual functions among hyperopic children. There was an association between near stereoacuity and near VA so that if a child had reduced function for one, he/she was more likely to have reduced function for the other. For example, among the 99 hyperopic children with reduced near stereoacuity, 52 (53%) had reduced near VA while only 33 (23%) of the 145 children with normal near stereoacuity had reduced near VA ($p<0.001$). There was no correlation between reduced stereoacuity and decreased accommodative response (increased accommodative lag) (>1.35D) as measured by Grand Seiko autorefraction. There was a weak association between reduced near VA and decreased accommodative response that was not statistically significant. Among the 85 children with near VA 20/40 or worse, 25 (29%) had increased accommodative lag while 34 (21%) of the 159 with VA better than 20/40 had this degree of lag ($p=0.21$).

Discussion

These results from the Vision in Preschoolers – Hyperopia in Preschoolers study show consistent and meaningful differences for each visual function (binocular near VA, accommodative response and near stereopsis) between emmetropic and uncorrected moderately hyperopic 4- and 5-year-old children without strabismus or amblyopia. Emmetropic children demonstrated significantly better visual performance overall compared to their hyperopic peers (3.0 to 6.0D). The percentage of children with one or more

reduced near visual functions was also higher among the hyperopes compared to the emmetropes representing a 5-fold difference between groups overall. Greater disparities were found as the magnitude of the hyperopia increased (3.5-fold for 3.0–3.25D, 5-fold for 3.5–3.75D and 7.4 fold for 4.0 D). While definitions for moderate hyperopia vary among studies, the increasing risk for poorer visual performance with increasing hyperopia noted for these near visual functions parallels the increasing risk of visual problems (e.g. amblyopia or strabismus) related to magnitude of hyperopia found in previous studies.^{9,11,18,26,27} With respect to accommodation, the results of this study support prior findings with regard to the increasing variability of accommodative response as hyperopia increases.^{26,27}

While participating children were excluded from having the more serious vision disorders of amblyopia and strabismus, they did demonstrate subtler reductions in visual performance. Previous studies have demonstrated associations between higher hyperopia and reduced acuity in bilateral amblyopia^{9,21,39}, increased variability in accommodative accuracy^{27,40–43} and reduced stereopsis⁹. The current study addresses the question of the co-occurrence of these reductions in individuals and was designed to study moderate hyperopes in the absence of amblyopia or strabismus.

Although there remains a lack of consensus for providing correction for moderate hyperopia^{44–46}, previous studies and clinical practice guidelines cite 4.0 to 4.5 diopters of uncorrected hyperopia as a threshold to consider prescribing^{9,47–50} or recommend monitoring VA and binocular function in addition to magnitude^{46,47,51} when managing hyperopia in young children. The results of this study provide support for these practices by showing a substantially increased risk for poorer visual performance in children with hyperopia of 4.0 diopters. In addition, this study also indicates that children with lower magnitudes of moderate hyperopia may also be at risk as approximately half of these children also demonstrated reduced near visual function (reduced accommodative response, near VA or near stereopsis). Finding an objective screening measure to better identify the hyperopic children who are at risk is therefore, an important goal for future research. Both the magnitude of the hyperopia and the presence of reduced visual functions may need to be considered for screening referrals and prescribing guidelines.

These results suggest that preschool age children with moderate uncorrected hyperopia have an increased likelihood for having one or more reduced visual functions compared to similar emmetropic children. In those hyperopic children with two or more reduced visual functions, there is also a greater likelihood that reduced near VA will be accompanied by reduced near stereoacuity. This association may reflect the prerequisite of sufficient near VA to resolve the random dot pattern of the near stereo test along with sustained near visual attention for both tasks. While adequate accommodation is also required for these functions, the clinical measure of accommodative response by Grand Seiko generally required less ‘on task’ time to complete as compared to the complexity of binocular near VA (up to approximately 15 matching trials to reach 20/20 using the modified ATS 4 protocol) or near stereopsis (up to approximately 20 matching trials to reach 30 sec arc using the PASS protocol) as performed in this study.

This cross-sectional observational study does not address potential causal relationships in these associations between refractive error and visual functions. Future investigations can use the associations found in this study to better understand how these occur and why there are differing responses among children with similar magnitudes of hyperopia.

It is currently unknown whether partial or full optical correction would either prevent or correct these decrements in visual performance in children with moderate hyperopia, either through direct reduction in accommodative effort or through restoration of typical visual experience and its impact on plastic synapses in the visual cortex. A number of prevention trials have studied the prevalence of strabismus and amblyopia after optical correction of hyperopia, and suggest that spectacle correction beginning in infancy reduces the prevalence of amblyopia at 4 years of age.^{8,52} The evidence regarding strabismus is more mixed.⁵³ The question of whether optical correction has any impact on the subtler reductions in visual performance noted here remains open.⁵⁴

While the presence of moderate hyperopia presented a consistent and measurably increased risk for reduced visual performance among children participating in the VIP-HIP study, this study also reports for the first time the existence of a subset of preschool aged children who retained good near visual functions (VA, accommodative response and stereoacuity) despite the presence of moderate uncorrected hyperopia. This included approximately 1/3 of the moderate hyperopes overall (3.0 to 6.0D) and also interestingly approximately 1/5 of the children with the higher amounts of moderate hyperopia (4.0D to 6.0D). It is not known from this study what other factors (e.g. familial, environmental, cognitive) may have influenced these differing visual function outcomes in children with the same magnitude of hyperopia. It is also not known if the children with reduced visual performance as found in this study are either at a greater risk for development of further degradation of vision in the future (including amblyopia or strabismus) or alternatively will have maturation and/or natural improvements in their visual skills with time and without corrective lens intervention.

The results of this study may also not be generalizable to the preschool population as a whole as the emmetropic and hyperopic cohorts participating in the VIP-HIP study overrepresented children enrolled in Head Start. While it is possible that the visual functions of these children may differ from those in other socioeconomic groups, a strength of the VIP-HIP population studied was that this was a large group of emmetropic and moderately hyperopic preschool aged children yet there were no significant differences between the refractive error groups with respect to age, sex, ethnicity or race, parent or guardian education level or enrollment (Head Start or other). Most importantly, the emmetropic children who participated in this study were shown to have average levels of preschool early literacy skills, similar to children in a general population.²⁸

The VIP-HIP study was a large National Institutes of Health sponsored study which found a relationship between hyperopia and significantly lower performance on a test of early literacy among preschool aged children who had the same demographic factors as their higher performing emmetropic peers.²⁸ This secondary analysis of the VIP-HIP data provides important new and clinically useful further insights into the relationship between

uncorrected hyperopia and near visual function in these preschool children without amblyopia or strabismus. These results may help further our understanding of which children with uncorrected refractive error may be at risk for visual dysfunction.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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APPENDIX

Credit Roster - VIP-HIP Study Group

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

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(4):739–746. [PubMed: 19243832]
2. Brody BL, Roch-Levecq AC, Klonoff-Cohen HS, Brown SI. Refractive errors in low income preschoolers. *Ophthalmic Epidemiol*. 2007; 14(4):223–229. [PubMed: 17896301]
3. Multi-Ethnic Pediatric Eye Disease Study Group. Prevalence and causes of visual impairment in African-American and Hispanic preschool children: the Multi-Ethnic Pediatric Eye Disease Study. Multi-Ethnic Eye Disease Study (MEPEDS) Group. *Ophthalmology*. 2009; 116(10):1990–2000. [PubMed: 19592106]
4. 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. Multi-Ethnic Eye Disease Study (MEPEDS) Group. *Ophthalmology*. 2010; 117(1):140–147. [PubMed: 19926137]
5. U.S. Census Bureau. School Enrollment; Current Population Survey. 2009 Nov. Document Number C9-C09-ALLF-06-US1.
6. Ingram RM. Refraction as a basis for screening children for squint and amblyopia. *Br J Ophthalmol*. 1977; 61(1):8–15. [PubMed: 836780]
7. Ip JM, Robaei D, Kifley A, Wang JJ, Rose KA, Mitchell P. Prevalence of hyperopia and associations with eye findings in 6- and 12- year-olds. *Ophthalmology*. 2008; 115(4):678–685. [PubMed: 17664011]
8. Atkinson J, Braddick O, Robier B, et al. Two infant vision screening programmes: prediction and prevention of strabismus and amblyopia from photo and videorefractive screening. *Eye*. 1996; 10(Pt 2):189–198. [PubMed: 8776448]
9. Kulp MT, Ying GS, Huang J, et al. VIP Study Group. Associations between hyperopia and other vision and refractive error characteristics. *Optom Vis Sci*. 2014; 91(4):383–389.
10. Birch EE, Fawcett SL, Morale SE, Weakley DR Jr, Wheaton DH. Risk factors for accommodative esotropia among hypermetropic children. *Invest Ophthalmol Vis Sci*. 2005; 46(2):526–529. [PubMed: 15671278]
11. Borchert MS, Varma R, Cotter SA, et al. Multi-Ethnic Pediatric Eye Disease Study and the Baltimore Pediatric Eye Disease Study Groups. Risk factors for hyperopia and myopia in preschool children the multi-ethnic pediatric eye disease and Baltimore pediatric eye disease studies. *Ophthalmology*. 2011; 118(10):1966–1973. [PubMed: 21856013]
12. Dobson V, Sebris SL. Longitudinal study of acuity and stereopsis in infants with or at-risk for esotropia. *Invest Ophthalmol Vis Sci*. 1989; 30(6):1146–1158. [PubMed: 2732029]
13. Pascual M, Huang J, Maguire MG, et al. Risk factors for amblyopia in the Vision in Preschoolers Study. *Ophthalmology*. 2014; 121(3):622–629. [PubMed: 24140117]
14. Abrahamsson M, Fabian G, Sjostrand J. Refraction changes in children developing convergent or divergent strabismus. *Br J Ophthalmol*. 1992; 76(12):723–727. [PubMed: 1486073]
15. Ingram RM, Walker C. Refraction as a means of predicting squint or amblyopia in preschool siblings of children known to have these defects. *Br J Ophthalmol*. 1979; 63(4):238–242. [PubMed: 435440]

16. Ingram RM, Traynar MJ, Walker C, Wilson JM. Screening for refractive errors at age 1 year: a pilot study. *Br J Ophthalmol*. 1979; 63(4):243–250. [PubMed: 435441]
17. Ingram RM, Walker C, Wilson JM, et al. Prediction of amblyopia and squint by means of refraction at age 1 year. *Br J Ophthalmol*. 1986; 70(1):12–15. [PubMed: 3947594]
18. Pai AS, Wang JJ, Samarawickrama C, et al. Prevalence and risk factors for visual impairment in preschool children the Sydney paediatric eye disease study. *Ophthalmology*. 2011; 118(8):1495–500. [PubMed: 21529955]
19. Robaei D, Rose KA, Kifley A, Cosstick M, Ip JM, Mitchell P. Factors associated with childhood strabismus: findings from a population based study. *Ophthalmology*. 2006; 113(7):1146–1153. [PubMed: 16675019]
20. Cotter SA, Varma R, Tarczy-Hornoch K, et al. Risk factors associated with childhood strabismus: the multi-ethnic pediatric eye disease and Baltimore pediatric eye disease studies. *Ophthalmology*. 2011; 118(11):2251–2261. [PubMed: 21856012]
21. Klimek DL, Cruz OA, Scott WE, Davitt BV. Isoametropic amblyopia due to high hyperopia in children. *J AAPOS*. 2004; 8(4):310–313. [PubMed: 15314589]
22. Tarczy-Hornoch K, Varma R, Cotter SA, et al. Risk factors for decreased visual acuity in preschool children: the multi-ethnic pediatric eye disease and Baltimore pediatric eye disease studies. *Ophthalmology*. 2011; 118(11):2262–2273. [PubMed: 21856014]
23. Colburn JD, Morrison DG, Estes RL, Li C, Lu P, Donahue SP. Longitudinal follow-up of hypermetropic children identified during preschool vision screening. *J AAPOS*. 2010; 14(3):211–215. [PubMed: 20603055]
24. Pai AS, Rose KA, Leone JF, et al. Amblyopia prevalence and risk factors in Australian preschool children. *Ophthalmology*. 2012; 119(1):138–144. [PubMed: 21963268]
25. von Noorden GK, Avilla CW. Accommodative convergence in hypermetropia. *Am J Ophthalmol*. 1990; 110(3):287–292. [PubMed: 2396654]
26. Mutti DO, Jones LA, Moeschberger ML, Zadnik K. AC/A ratio, age, and refractive error in children. *Invest Ophthalmol Vis Sci*. 2000; 41(9):2469–2478. [PubMed: 10937556]
27. Candy TR, Gray KH, Hohenbary CC, Lyon DW. The accommodative lag of the young hyperopic patient. *Invest Ophthalmol Vis Sci*. 2012; 53:143–149. [PubMed: 22125280]
28. Kulp MT, Ciner E, Maguire M, Moore B, Pentimonti J, Pistilli M, Cyert L, Candy TR, Quinn G, Ying GS. VIP-HIP Study Group; Writing Committee. Uncorrected Hyperopia and Preschool Early Literacy: Results of the Vision in Preschoolers-Hyperopia in Preschoolers (VIP-HIP) Study. *Ophthalmology*. 2016 Apr; 123(4):681–689. [PubMed: 26826748]
29. Vision In Preschoolers (VIP) Study Group. Implementation of a preschool vision screening program in a mobile setting. *The NHSA Dialog*. 2005; 8:16–24.
30. Drover JR, Felius J, Cheng CS, Morale SE, Wyatt L, Birch EE. Normative pediatric visual acuity using single surrounded HOTV optotypes on the Electronic Visual Acuity Tester following the Amblyopia Treatment Study protocol. *J AAPOS*. 2008; 12(2):145–149. [PubMed: 18155943]
31. Kulp MT, Dobson V, Peskin E, Quinn G, Schmidt P, Vision in Preschoolers Study Group. The electronic visual acuity tester: testability in preschool children. *Optom Vis Sci*. 2004; 81(4):238–244. [PubMed: 15097765]
32. Repka MX, Cotter SA, Beck RW, et al. Pediatric Eye Disease Investigator Group. A randomized trial of atropine regimens for treatment of moderate amblyopia in children. *Ophthalmology*. 2004; 111(11):2076–2085. [PubMed: 15522375]
33. Christoff A, Repka MX, Kaminski BM, Holmes JM. Pediatric Eye Disease Investigator Group. Distance versus near visual acuity in amblyopia. *J AAPOS*. 2011; 15(4):342–344. [PubMed: 21907115]
34. Ciner EB, Ying GS, Kulp MT, et al. Vision in Preschoolers Study Group. Stereoacuity of preschool children with and without vision disorders. *Optom Vis Sci*. 2014; 91(3):351–358. [PubMed: 24463769]
35. Schmidt PP, Maguire MG, Moore B, Cyert L. Vision in Preschoolers Study Group. Testability of preschoolers on stereotests used to screen vision disorders. *Optom Vis Sci*. 2003; 80(11):753–757. [PubMed: 14627942]

36. McClelland JF, Saunders KJ. Accommodative lag using dynamic retinoscopy: age norms for school-age children. *Optom Vis Sci.* 2004; 81(12):929–933. [PubMed: 15592117]
37. Mutti DO, Mitchell GL, Hayes JR, et al. Accommodative lag before and after the onset of myopia. *Invest Ophthalmol Vis Sci.* 2006; 47(3):837–846. [PubMed: 16505015]
38. Manny RE, Chandler DL, Scheiman MM, et al. Accommodative lag by autorefraction and two dynamic retinoscopy methods. *Optom Vis Sci.* 2009; 86(3):233–243. [PubMed: 19214130]
39. Fern KD. Visual acuity outcome in isometropic hyperopia. *Optom Vis Sci.* 1989; 66(10):649–658. [PubMed: 2587031]
40. Ingram RM, Gill LE, Goldacre MJ. Emmetropisation and accommodation in hypermetropic children before they show signs of squint--a preliminary analysis. *Bull Soc Belge Ophthalmol.* 1994; 253:41–56.
41. Mutti DO, Mitchell GL, Jones LA, et al. Accommodation, acuity, and their relationship to emmetropization in infants. *Optom Vis Sci.* 2009; 86(6):666–676. [PubMed: 19417711]
42. Horwood AM, Riddell PM. Hypo-accommodation responses in hypermetropic infants and children. *Br J Ophthalmol.* 2011; 95(2):231–237. [PubMed: 20603431]
43. Tarczy-Hornoch K. Accommodative lag and refractive error in infants and toddlers. *J AAPOS.* 2012; 16(2):112–117. [PubMed: 22424817]
44. Lyons SA, Jones LA, Walline JJ, et al. A survey of clinical prescribing philosophies for hyperopia. *Optom Vis Sci.* 2004; 81(4):233–237. [PubMed: 15097764]
45. Leat SJ, Mittelstaedt A, McIntosh S, Machan CM, Hrynychak PK, Irving EL. Prescribing for hyperopia in childhood and teenage by academic optometrists. *Optom Vis Sci.* 2011; 88(11):1333–1342. [PubMed: 21892114]
46. Cotter SA. Management of childhood hyperopia: a pediatric optometrist's perspective. *Optom Vis Sci.* 2007; 84(2):103–109. [PubMed: 17299339]
47. Donahue SP. Prescribing spectacles in children: a pediatric ophthalmologist's approach. *Optom Vis Sci.* 2007; 84(2):110–114. [PubMed: 17299340]
48. Royal College of Ophthalmologists. Guidelines for the Management of Amblyopia. [Accessed February 21, 2010] Available at: <http://www.rcophth.ac.uk/docs/publications/GuidelinesfortheManagementofAmblyopia.pdf>.
49. American Academy of Ophthalmology. ONE™ Network. Preferred Practice Patterns. Amblyopia PPP. 2007 [Accessed July 7, 2011] Available at: http://one.aao.org/ce/practiceguidelines/ppp_content.aspx?cid_930d01f2-740b-433e-a973-cf68565bd27b.
50. Miller JM, Harvey EM. Spectacle prescribing recommendations of AAPOS members. *J AAPOS.* 1998; 35(1):51–52.
51. American Optometric Association. Optometric Clinical Practice Guideline: Care of the Patient with Hyperopia. [Accessed July 14, 2010] Available at: <http://www.aoa.org/documents/CPG-16.pdf>.
52. Ingram RM, Lambert TW, Gill LE. Visual outcome in 879 children treated for strabismus: insufficient accommodation and vision deprivation, deficient emmetropisation and anisometropia. *Strabismus.* 2009; 17(4):148–157. [PubMed: 20001509]
53. Jones-Jordan L, Wang X, Scherer RW, Mutti DO. Spectacle correction versus no spectacles for prevention of strabismus in hyperopic children. *Cochrane Database Syst Rev.* 2014 Aug 18.8:CD007738.
54. Atkinson J, Braddick O, Nardini M, Anker S. Infant hyperopia: detection, distribution, changes and correlates V outcomes from the Cambridge infant screening programs. *Optom Vis Sci.* 2007; 84(2):84–96. [PubMed: 17299337]

Biographies

Table 1

Characteristics of participating children by refractive error group

Characteristics	Emmetropic N=248	Hyperopic N=244	p-value
Demographic			
Age in months, n (%)			
48 – 53	58 (23%)	73 (30%)	
54 – 59	86 (35%)	79 (32%)	
60 – 65	80 (32%)	72 (30%)	
66 – <72	24 (10%)	20 (8%)	
Mean (SD)	58.7 (5.5)	58.0 (5.8)	0.43
Sex, n (%)			
Male	128 (52%)	114 (47%)	
Female	120 (48%)	130 (53%)	0.28
Ethnicity and race, n (%)			
Non-hispanic black	150 (60%)	140 (57%)	
Non-hispanic white	20 (8%)	28 (11%)	
Hispanic	61 (25%)	63 (26%)	
Other or unknown	17 (7%)	13 (5%)	0.53
Education level of parent or caregiver, n (%)			
Less than high school	18 (7%)	27 (11%)	0.35
High school	92 (37%)	102 (42%)	
Some college	55 (22%)	39 (16%)	
2-yr college	21 (8%)	22 (9%)	
4-yr college	23 (9%)	23 (9%)	
Graduate degree	19 (8%)	12 (5%)	
Unknown	20 (8%)	19 (8%)	
Preschool/Kindergarten, n (%)			
Head Start	224 (90%)	215 (88%)	
Other Preschool/Kindergarten	24 (10%)	29 (12%)	0.43
Ocular*			
Most hyperopic meridian, more hyperopic	0.51 (0.48)	3.78 (0.81)	---

Characteristics	Emmetropic N=248	Hyperopic N=244	p-value
eye, diopters, Mean (SD)			
Spherical equivalent, more hyperopic eye, diopters, Mean (SD)	0.37 (0.50)	3.47 (0.81)	---
Anisometropia, diopters, Mean (SD)	0.17 (0.19)	0.40 (0.30)	<0.001
Astigmatism, more astigmatic eye, diopters, Mean (SD)	0.40 (0.24)	0.72 (0.41)	<0.001

* p-values for sphere and equivalent are not provided because they define the two groups. The eligibility criterion for astigmatism was different for emmetropes (<1D) and hyperopes (1.5D), thus they were unlikely to be similar.

SD = standard deviation

Table 2

Visual function by refractive error group

Visual function	Emmetropic (N=248)	Hyperopic (N=244)	p-value
Distance visual acuity, better eye			
Better than 20/20	35 (14%)	10 (4%)	
20/20	98 (40%)	43 (18%)	
20/25	75 (30%)	72 (30%)	
20/32	34 (14%)	84 (34%)	
20/40	6 (2%)	35 (14%)	
Median (25%, 75%), Snellen	20/20 (20/20, 20/25)	20/25 (20/25, 20/32)	
Mean (SD), LogMAR	0.05 (0.10)	0.14 (0.11)	<0.001
Distance visual acuity, worse eye			
Better than 20/20	18 (7%)	1 (0%)	
20/20	67 (27%)	20 (8%)	
20/25	87 (35%)	64 (26%)	
20/32	57 (23%)	83 (34%)	
20/40	19 (8%)	74 (30%)	
Worse than 20/40	0 (0%)	2 (1%)	
Median (25%, 75%), Snellen	20/25 (20/20, 20/32)	20/32 (20/25, 20/40)	
Mean (SD), LogMAR	0.10 (0.11)	0.19 (0.10)	<0.001
Near visual acuity, binocular			
20/20	59 (24%)	13 (5%)	
20/25	95 (38%)	69 (28%)	
20/32	67 (27%)	77 (32%)	
20/40	22 (9%)	64 (26%)	
Worse than 20/40	5 (2%)	21 (9%)	
Median (25%, 75%), Snellen	20/25 (20/25, 20/32)	20/32 (20/25, 20/40)	
Mean (SD), LogMAR	0.13 (0.11)	0.21 (0.11)	<0.001
Accommodative response, by Monocular Estimation Method, diopters			
0 – 0.5	58 (23%)	19 (8%)	
>0.5 – 1	84 (34%)	26 (11%)	
>1 – 1.5	75 (30%)	37 (15%)	
>1.5 – 2.01	22 (9%)	53 (22%)	
>2.01	9 (4%)	109 (45%)	
Median (25%, 75%)	1.00 (0.63, 1.38)	2.00 (1.38, 2.50)	
Mean (SD)	1.03 (0.51)	2.03 (1.03)	<0.001
Accommodative response, by Grand Seiko, diopters			
0 – 0.5	161 (65%)	93 (38%)	
>0.5 – 1	62 (25%)	66 (27%)	
>1 – 1.35	18 (7%)	26 (11%)	

Visual function	Emmetropic (N=248)	Hyperopic (N=244)	p-value
>1.35 – 2	3 (1%)	30 (12%)	
>2	4 (2%)	29 (12%)	
Median (25%, 75%)	0.32 (0.16, 0.63)	0.67 (0.34, 1.31)	
Mean (SD)	0.46 (0.45)	0.99 (1.00)	<0.001
Stereoacuity by Preschool Assessment of Stereopsis with a Smile, seconds of arc			
Unable	0 (0%)	1 (0%)	
Demonstration card only	3 (1%)	30 (12%)	
480	2 (1%)	27 (11%)	
240	8 (3%)	41 (17%)	
120	50 (20%)	81 (33%)	
60	38 (15%)	24 (10%)	
40	87 (35%)	24 (10%)	
30	60 (24%)	16 (7%)	
Median (25%, 75%)	40 (40, 120)	120 (60, 240)	<0.001 *

* For stereoacuity the median and interquartile range are provided because the data are skewed, and the p-value calculation for the comparison of means was calculated on log-transformed seconds of arc.

SD = standard deviation

Table 3

Reduced visual functions by refractive error

Sphere	N	Number of reduced visual functions				p-value*
		0	1	2	3	
Emmetropes	248	206 (83%)	37 (15%)	5 (2%)	0 (0%)	<0.001
Hyperopes (all)	244	87 (36%)	87 (36%)	54 (22%)	16 (7%)	
Hyperopes (by sphere):						
3–3.25D	102	52 (51%)	35 (34%)	12 (12%)	3 (3%)	<0.001
3.5–3.75D	57	20 (35%)	20 (35%)	16 (28%)	1 (2%)	
4–6D	85	15 (18%)	32 (38%)	26 (31%)	12 (14%)	

SE = standard error of the mean

Table 4

Visual functions by refractive error among hyperopes

Visual function	3-4D (N=159)	4-6D (N=85)	Difference (95% CI)	p-value*
Distance visual acuity, better eye (mean LogMAR)	0.12	0.17	0.05 (0.02, 0.07)	0.001
Distance visual acuity, worse eye (mean LogMAR)	0.18	0.21	0.04 (0.01, 0.06)	0.006
Near visual acuity, binocular (mean LogMAR)	0.19	0.25	0.06 (0.03, 0.09)	<0.001
Accommodative response, by Monocular Estimation Method (mean diopters)	1.73	2.59	0.86 (0.61, 1.11)	<0.001
Accommodative response, by Grand Seiko, diopters (mean diopters)	0.83	1.28	0.45 (0.19, 0.71)	<0.001
Stereoacuity by Preschool Assessment of Stereopsis with a Smile (median seconds of arc)	120	240	n/a	<0.001
Anisometropia (mean diopters)	0.39	0.43	0.04 (-0.03, 0.12)	0.27
Astigmatism (mean diopters)	0.69	0.78	0.09 (-0.02, 0.20)	0.10

CI = confidence interval

Table 5

Distribution of reduced visual functions for the 244 hyperopes

Accommodation by Grand Seiko >1.35D	Near visual acuity 20/40 or worse	Stereoacuity 240 seconds of arc or worse	n (%)
No	No	No	87 (36%)
No	No	Yes	38 (16%)
No	Yes	No	24 (10%)
Yes	No	No	25 (10%)
No	Yes	Yes	36 (15%)
Yes	No	Yes	9 (4%)
Yes	Yes	No	9 (4%)
Yes	Yes	Yes	16 (7%)