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Attention and Visual Motor Integration in Young Children with Uncorrected Hyperopia

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Abstract

Significance—Among 4- and 5- year-old children, deficits in measures of attention, visual-motor integration (VMI) and visual perception (VP) are associated with moderate, uncorrected hyperopia (3–6D) accompanied by reduced near visual function (near visual acuity worse than 20/40 or stereoacuity worse than 240 seconds of arc).

Purpose—To compare attention, visual motor and visual perceptual skills in uncorrected hyperopes and emmetropes attending preschool or kindergarten, and evaluate their associations with visual function.

Methods—Participants were 4 and 5 years of age with either hyperopia (−3D to −6D, astigmatism ≤1.5D, anisometropia ≤1D) or emmetropia (hyperopia ≤1D; astigmatism, anisometropia, and myopia each <1D), without amblyopia or strabismus. Examiners masked to refractive status administered tests of attention (sustained, receptive and expressive), VMI, and VP. Binocular visual acuity (VA), stereoacuity, and accommodative accuracy were also assessed at near. Analyses were adjusted for age, sex, race/ethnicity, and parent/caregiver's education.

Results—244 hyperopes (mean +3.8D±SD0.8) and 248 emmetropes (+0.5D±0.5) completed testing. Mean sustained attention score was worse in hyperopes compared to emmetropes (mean difference: −4.1, $p<0.001$ for 3–6D). Mean receptive attention score was worse in 4–6D hyperopes compared to emmetropes (by −2.6, $p=0.01$). Hyperopes with reduced near VA (20/40 or worse) had worse scores than emmetropes (−6.4, $p<0.001$ for sustained attention; −3.0, $p=0.004$ for receptive attention; −0.7, $p=0.006$ for VMI, −1.3, $p=0.008$ for VP). Hyperopes with stereoacuity of 240 arc secs or worse scored significantly worse than emmetropes (−6.7, $p<0.001$ for sustained attention; −3.4, $p=0.03$ for expressive attention, −2.2, $p=0.03$ for receptive attention; −0.7, $p=0.01$

for VMI, -1.7 , $p < 0.001$ for VP). Overall, hyperopes with better near visual function generally performed similarly to emmetropes.

Conclusions—Moderately hyperopic children were found to have deficits in measures of attention. Hyperopic children with reduced near visual function also had lower scores on VMI and VP than emmetropic children.

Keywords

hyperopia; children; attention; visual-motor integration

Moderate hyperopia of 3 diopters (D) or more has been reported to affect 4.4% to 14.1% of preschool children.^{1, 2} While some suggest that young children with uncorrected, moderate hyperopia have the necessary accommodative ability to provide sustained clear vision at near viewing distances,³ Anderson et al. have recently shown that the amplitude of accommodation of young children may be lower than previously thought.⁴ Furthermore, accommodation is less accurate in preschoolers than in older children and accommodative lag increases and becomes more variable with increasing demand.⁵ The need for extra accommodative effort in uncorrected hyperopia may result in symptoms such as eyestrain, headache, intermittent blur and difficulty attending at near, potentially resulting in academic problems.^{6–8}

Prior research has shown a relationship between reduced early literacy acquisition and hyperopia.^{9,10} In the Vision in Preschoolers-Hyperopia in Preschoolers (VIP-HIP) Study, children with uncorrected hyperopia of 3 to 6D accompanied by reduced near visual acuity or stereoacuity scored significantly worse on a test of early literacy.⁹ A small number of studies have also investigated the relationship between hyperopia and other academic skills. Atkinson et al reported that attention is decreased in young children with hyperopia.¹¹ Contradictory results have been found regarding the relationship between hyperopia and visual motor skills in young children.^{10–13} Prior research on the relationship between hyperopia and these skills has not, however, evaluated the role of near visual function and uncorrected hyperopia on attention and visual motor skills. The purpose of the current paper from the VIP-HIP Study was to determine whether 4- and 5-year-old children with uncorrected hyperopia (3 to 6D) perform worse on assessments of attention, visual motor and visual perceptual skills than emmetropic children. None of the children were amblyopic or strabismic. The relationship between moderate hyperopia and test performance for attention, visual motor skills and visual perceptual skills was further investigated by evaluating the role of near visual function (accommodative accuracy, binocular visual acuity and stereoacuity at near) in any relationships found.

METHODS

The multicenter VIP-HIP Study design and methods have been described previously in detail.⁹ In brief, participating children were ages 4 and 5 years and were attending preschool or kindergarten. Children who had previously worn correction for refractive error, had amblyopia or strabismus, or were in an Individualized Education Program for developmental, educational, or behavioral issues were excluded. All testing was performed

by study-certified examiners experienced in working with young children. Eye examiners were licensed eye care professionals. Educational assessors had a bachelor's degree or higher in education or psychology. Testing was performed at one of the participating clinical centers or in a Vision in Preschooler mobile unit¹⁴ at the child's school that provided a comparable testing environment and greater access to participation for families. The study adhered to the tenets of the Declaration of Helsinki. Institutional Review Board approval was obtained at each participating center (Salus University, Pennsylvania College of Optometry, Elkins Park, Pennsylvania; The Ohio State University College of Optometry, Columbus, Ohio; and New England College of Optometry, Boston, MA). Written parental informed consent was obtained prior to performing any study procedures.

A comprehensive eye examination was performed to determine eligibility based on cycloplegic auto-refraction, to rule out the presence of amblyopia and strabismus, and to assess near visual functions (accommodative accuracy, near visual acuity, and stereoacuity). Monocular visual acuity testing was performed at distance (Amblyopia Treatment Study protocol)¹⁵. If reduced visual acuity was found on initial testing (visual acuity worse than 20/40 or interocular difference of two or more lines), visual acuity testing with full correction was repeated after cycloplegia. Children with suspected amblyopia were excluded (reduced visual acuity with full correction in the presence of an amblyogenic factor). Cover testing was performed at distance and near and children with strabismus were excluded from participation. Binocular near visual acuity was measured at 40 cm using lines of single-surrounded HOTV optotypes (ATS4 Near Acuity Test; Precision Vision, Chicago, IL). Preschool Assessment of Stereopsis with a Smile was performed at 40 cm (480, 240, 120, 60, 40, and 30 seconds of arc). Accommodative accuracy was assessed at 33 cm while children viewed a detailed sticker of a popular cartoon character, using the Grand Seiko Autorefractor. Eligibility for the hyperopia group (3 to 6D in the most hyperopic meridian of at least one eye with anisometropia 1D and astigmatism 1.5D in both eyes) or for the emmetropic group (both eyes having hyperopia 1D, astigmatism, anisometropia, and myopia all <1D) was determined by cycloplegic autorefraction following cycloplegia with 1% cyclopentolate.

Eligible children returned for educational testing on a separate day. Examiners who were masked to the child's refractive status administered tests of visual motor integration, visual perception and attention (Leiter-R followed by Cognitive Assessment System Expressive and Receptive Attention). Testing was performed in this order for all children. Testing was administered according to the instructions in the user's manual for each test, with the exception that the Cognitive Assessment System attention testing was administered to all participating children (4- and 5-year-olds) in consultation with the test's author. While the Cognitive Assessment System only includes normative values for children starting at age 5 years, we compared scores between hyperopic and emmetropic children rather comparing scores to normative values and it was expected that 4-year-olds would be able to complete the test. Children were given a break and offered a snack during testing as needed to keep them engaged in the testing session.

The Leiter-R (Leiter) Attention Sustained subtest is a non-verbal measure of sustained attention whose reliability and validity have been previously defined.¹⁶ Children were

presented with a series of pages of pictures and were instructed to cross out as many of the pictures as possible that match a reference picture at the top of the page. The Leiter booklet B was used which included 4 parts (AS5, AS6, AS7, AS8) with increasing difficulty. The testing time for each of the first 3 parts was 30 seconds and the testing time for the fourth part (AS8) was 60 seconds. Each part included an associated teaching trial and only children able to successfully complete the teaching trial continued on to testing for that part. Each part consisted of an array of pictures (AS5: 54 pictures in 6 rows; AS6: 77 pictures in 7 rows, AS7: 96 pictures in 8 rows, and AS8: 81 pictures [not arranged in regular rows]). The score for each part was the total correct minus total incorrect, with zero as the lowest possible score. The total score was the sum of the scores from the 4 parts.

The Cognitive Assessment System is a norm referenced test whose psychometric qualities of reliability and validity have been carefully studied.^{17–19} Subtests of attention include Receptive and Expressive Attention. Receptive Attention testing included four test items, each with 50 pairs of pictures. Testing time for each item was 120 seconds. The child was asked to underline the pairs of pictures that were identical (first two test items) or the same concept (last two test items). Testing included two prior demonstration sample items (one before the first two test items and a second before the last two test items), which had to be completed successfully for testing to proceed. The test raw score was the total number of correctly identified pairs minus the number of underlined picture groups that were not correct pairs (false detections) for all 4 test items combined.

The Cognitive Assessment System Expressive Attention test required the child to verbally identify the animals pictured as large or small animals (e.g. say “big” or “little”), regardless of relative size of pictures on the test page. The test consisted of 3 items, each with a testing time of 180 seconds. The first item contained pictures that were all the same size, the second item contained pictures of animals that were consistent with their true size, and the third item contained pictures that were often inconsistent with their true size. Only the third item was scored. Each test item was preceded by a test sample, which the child had to successfully complete to proceed with testing. The child was permitted to use a finger to help keep his/her place.

The Beery-Buktenica Developmental Test of Visual-Motor Integration, 5th Edition²⁰ (Visual-Motor Integration) is an untimed assessment of the extent to which children are able to integrate their visual and motor abilities. The child was asked to copy drawings of increasing difficulty. Its supplemental test of Visual Perception²⁰ includes the same 24 forms as the Visual-Motor Integration but in a motor-demand reduced, multiple-choice format in order to assess Visual Perception without the influence of motor skill or visual-motor integration. The Visual Perception test is timed for a duration of 3 minutes.

Data and Statistical Analysis

Determination of Leiter, Cognitive Assessment System, Visual-Motor Integration and Visual Perception raw scores for each child followed scoring guidelines in the user’s manual for each test. We compared the mean raw scores between hyperopes and emmetropes using analysis of variance. Comparisons were also performed using linear regression models with adjustment for covariates, specifically chronologic age at the time of the educational

assessment, sex, parental education status, and race/ethnicity. The effect of magnitude of hyperopia was assessed using linear regression models by comparing mean scores between children with emmetropia, hyperopia ≥ 3 to <4 D, and hyperopia ≥ 4 to ≤ 6 D (most hyperopic meridian), with the cut point selected based upon the findings of Candy et al, that children with more than 4D of hyperopia (in their most accurate meridian for accommodation) had more variable accommodative lag across the group.²¹ Mean scores were also compared for children with emmetropia and hyperopia as a function of accommodative lag, binocular near visual acuity, and near stereoacuity. The mean difference between groups and the associated 95% confidence intervals (95% CI) were calculated by including two indicator variables in the regression model to specify three groups (Tables 2 to 5) and specifying specific contrasts of the regression coefficients for the two indicator variables. The cut points for these categories of reduced visual function were based on the distributions among the emmetropes (accommodative lag >1.35 D, binocular near visual acuity 20/40 or worse, and stereoacuity ≥ 240 seconds of arc or worse).⁹ Accommodative lag was calculated as an average of five Grand Seiko measurements from the subject's most accurate meridian (focused closest to the target). The Hochberg procedure²² was used to adjust for the multiple comparisons among emmetropes, hyperopes without reduced visual function, and hyperopes with reduced visual function.

RESULTS

Eligibility criteria were met and educational testing was completed by 244 hyperopes and 248 emmetropes. There were no significant differences between the hyperopic and emmetropic children in mean age (hyperopes: mean $58.5 \pm \text{SD } 5.8$ months, emmetropes: 59.2 ± 5.5 months), sex, parent/caregiver's education level, percentage enrolled in Head Start, or race/ethnicity. The majority of children in both groups were enrolled in Head Start (hyperopes: 88%, emmetropes: 90%). Head Start is a national, comprehensive child development program of the United States Department of Health and Human Services that serves low-income preschool children and their families with a goal of increasing the school readiness of enrolled children. The mean refractive error (most hyperopic meridian, more hyperopic eye) was $+3.78\text{D} \pm 0.81$ in the hyperopes and $+0.51\text{D} \pm 0.48$ in the emmetropes. Additional details regarding characteristics of participating children have been published previously.⁹

The mean Leiter score in hyperopic children (≥ 3 to ≤ 6 D) was significantly worse than in emmetropic children (-4.1 [95% CI: $-6.4, -1.8$], $p < 0.001$), after adjustment for age, sex, race/ethnicity, and parent/caregiver's education (Table 1). A borderline significant difference was present between hyperopic and emmetropic children in Cognitive Assessment System Receptive Attention. There was no significant difference between hyperopic and emmetropic children in Cognitive Assessment System Expressive Attention, Visual-Motor Integration or Visual Perception score (Table 1).

Analyses to determine the effect of the magnitude of hyperopia on the test scores showed that the mean adjusted Leiter score was significantly worse for children with ≥ 3 to <4 D of hyperopia (-3.4 [$-6.0, -0.8$], $p = 0.02$) or ≥ 4 to ≤ 6 D of hyperopia (-5.3 [$-8.5, -2.1$], $p = 0.004$) than for those with emmetropia (Table 2). In addition, the mean adjusted Cognitive

Assessment System Receptive Attention score was significantly worse for children with 4 to 6D of hyperopia than for those with emmetropia (-2.6 [-4.4 , -0.8], $p=0.01$) or 3 to <4 D of hyperopia (-2.3 [-4.2 , -0.4], $p=0.04$). There were no statistically significant differences in adjusted mean score among the three groups of children for Cognitive Assessment System Expressive Attention, Visual-Motor Integration or Visual Perception tests (Table 2).

Analyses to assess the effect of accommodative accuracy (as measured by Grand Seiko autorefraction) revealed that children with hyperopia had worse scores on the Leiter regardless of accommodative accuracy (-4.0 [-6.4 , -1.5], $p=0.005$ for hyperopes with 1.35D lag; -4.6 [-8.3 , -0.8], $p=0.03$ for hyperopes with >1.35 D lag) (Table 3). Hyperopic children with the poorest accommodative accuracy (greatest lags) had worse mean scores on Cognitive Assessment System Receptive Attention as compared to emmetropic children (-4.2 [-6.2 , -2.1], $p<0.001$) or hyperopic children with 1.35D lag (-4.0 [-6.1 , -1.9], $p<0.001$) (Table 3). There were no significant differences in adjusted mean score among the three groups of children for Cognitive Assessment System Expressive Attention, Visual-Motor Integration or Visual Perception score.

Analysis to investigate associations with binocular near visual acuity revealed that the mean scores of hyperopes with binocular near visual acuity of 20/40 or worse were significantly worse than those of emmetropic children (-6.4 [-9.7 , -3.2], $p<0.001$ for Leiter; -3.0 [-4.8 , -1.2], $p=0.004$ for Cognitive Assessment System Receptive Attention; -0.7 [-1.3 , -0.2], $p=0.006$ for Visual-Motor Integration; -1.3 [-2.2 , -0.3] $p=0.008$ for Visual Perception) or hyperopic children with binocular near visual acuity better than 20/40 (-3.5 [-7.0 , -0.0], $p=0.0495$ for Leiter; -2.7 [-4.6 , -0.8], $p=0.01$ for Cognitive Assessment System Receptive Attention; -0.7 [-1.3 , -0.2], $p=0.01$ for Visual-Motor Integration; -1.3 [-2.3 , -0.3], $p=0.01$ for Visual Perception). A smaller, but statistically significant deficit in Leiter score was observed for hyperopes with binocular near visual acuity better than 20/40 than emmetropes (-2.9 [-5.5 , -0.4], $p=0.0495$). The adjusted mean Cognitive Assessment System Receptive Attention, Visual-Motor Integration and Visual Perception scores of hyperopes with binocular near visual acuity better than 20/40 were equivalent to those of emmetropes ($p=0.74$) (Table 4). There were no statistically significant differences in adjusted mean score among the three groups of children for Cognitive Assessment System Expressive Attention testing as a function of binocular near visual acuity.

Analyses to determine whether near stereoacuity was associated with test performance showed that the scores of hyperopic children with near stereopsis of 240 seconds of arc or worse were significantly worse than those of emmetropic children (-6.7 [-9.8 , -3.7], $p<0.001$ for Leiter; -3.4 [-6.1 , -0.7], $p=0.03$ for Cognitive Assessment System Expressive Attention; -2.2 [-3.9 , -0.5], $p=0.03$ for Cognitive Assessment System Receptive Attention; -0.7 [-1.2 , -0.2], $p=0.01$ for Visual-Motor Integration; -1.7 [-2.5 , -0.8], $p<0.001$ for Visual Perception) or hyperopic children with near stereopsis better than 240 seconds of arc (-4.5 [-7.8 , -1.1], $p=0.02$ for Leiter; -3.8 [-6.7 , -0.8], $p=0.03$ for Cognitive Assessment System Expressive Attention, -0.8 [-1.3 , -0.2], $p=0.01$ for Visual-Motor Integration; -2.0 [-3.0 , -1.1], $p<0.001$ for Visual Perception). The mean adjusted scores of emmetropes and hyperopes with near stereopsis better than 240 seconds of arc were not significantly different ($p=0.10$ for all comparisons) (Table 5).

DISCUSSION

As part of our effort to understand whether there are differences in educational performance between children with moderate, uncorrected hyperopia versus emmetropia,⁹ we compared performance on assessments of attention, visual-motor integration and visual perception in the VIP-HIP cohort of emmetropic and uncorrected hyperopic (3 to 6D) 4- and 5-year-old children without strabismus or amblyopia. We found statistically significant deficits in sustained visual attention for hyperopic children relative to emmetropic children.

These results suggest that poorer sustained, receptive visual attention (the child's ability to selectively attend to some visual stimuli and ignore others) is associated with increasing uncorrected hyperopia, particularly when 4D or in the presence of reduced near visual function. Small, but meaningful, effect sizes (difference in means between groups/standard deviation within groups) of approximately 0.3 to 0.4 were associated with the statistically significant differences noted above.²³ The observed differences are likely to be associated with an inability to sustain attention and/or focus rather than an inability to resolve the targets. The fact that each child demonstrated the ability to complete the teaching trial or sample for each test prior to completing the test supports the premise that each child could resolve the test items. The test images are approximately 0.8 cm to 2 cm in size with pen stroke width corresponding to an acuity equivalent of approximately 20/54 for Leiter and 20/36 for Cognitive Assessment System Receptive Attention testing. The differences between pictures that must be detected in order to complete the task are found at lower spatial frequencies. Finally, if differences were due to difficulty with resolving the targets, one would expect smaller differences for Leiter than for the Cognitive Assessment System Receptive Attention; the opposite was observed.

Children with hyperopia performed worse on the Leiter test of attention regardless of accommodative accuracy, while hyperopic children with the poorest accommodative accuracy (greatest accommodative lag) scored significantly lower on Cognitive Assessment System Receptive Attention testing. This may be attributable to differences in cognitive and/or visual demand between the two tests.

These results are consistent with the findings of Mezer et al who reported an association between attention deficit hyperactivity disorder and presence of refractive error such as hyperopia.²⁴ They are also consistent with Atkinson et al. who found deficits in selective visual attention for standardized subtests from the Test of Everyday Attention for Children with 6- to 7-year-old hyperopic children.¹¹ The authors reported that the deficits in attention were found only for tests involving processing of visual information, and not for those involving processing of auditory information.¹¹

The current study showed no significant difference in visual-motor integration and visual perception between emmetropes and hyperopes overall, but showed statistically significant deficits with small effect sizes (approximately 0.3 to 0.4) in visual-motor integration and visual perception for hyperopic children with reduced near visual function (decreased binocular near visual acuity or stereoacuity). Given that the visual-motor integration stimuli are large and of high contrast (approximately 20/300), the association between reduced near

visual function and visual-motor integration and visual perception score cannot be attributed to difficulty resolving the visual-motor integration test items, but rather are likely due to difficulties with sustained focus and/or acquisition of visual motor skills.

Prior studies of visual motor skill in young children with hyperopia have shown contradictory findings. Atkinson and colleagues showed that children who were hyperopic ($+3.5D$ or more in at least one meridian) at 9 months of age performed significantly worse than non-hyperopic children on a battery of visuomotor and visuocognitive tests at 5.5 years of age.¹² A follow-up study at age 6 years again revealed visuomotor deficits on the Movement ABC.¹¹ Roch-Levecq et al. found significantly lower scores on the Wechsler Preschool and Primary Scale of Intelligence-Revised (WPPSI-R) and the Developmental Test of Visual-Motor Integration for 35 children with uncorrected bilateral hyperopia and/or astigmatism compared to 35 age-matched emmetropic controls ($-2D$ of hyperopia and $-1D$ astigmatism).¹³ When the children were retested after wearing correction for six weeks, the test score differences between the refractive error group and the emmetropic group were no longer statistically significant. On the other hand, Shankar et al.¹⁰ found no difference in visual-motor integration or visual spatial skill between 13 children with uncorrected hyperopia ($-2D$) and 19 emmetropic children ($-1.5D$). The results of the VIP-HIP Study agree with prior research showing a relationship between hyperopia and visuomotor¹² or visual-motor integration¹³ for hyperopic children with reduced near visual function. On the other hand, the results also agree with prior research showing no differences in visual-motor integration or visual spatial skill¹⁰ for hyperopic children without reduced near visual function. Therefore, this suggests that the different relationships between hyperopia and visual motor skill in this literature may be due to sample size effects and differences in near visual function among participating hyperopes.

A high percentage of children in the current study were enrolled in Head Start. It is possible that the results may have been different for children from a higher socioeconomic group. However, there was no difference between groups in the percentage of children who were enrolled in Head Start. Furthermore, all comparisons were performed with adjustment for covariates potentially affecting test scores, such as age, sex, parental education status, and race/ethnicity.

Further research is needed to determine the effect of refractive correction on the deficits in attention, visual motor, and visual perceptual skills identified here and the deficits in near visual functions and preschool literacy identified in previous reports.⁹⁻¹³ It is important to determine whether correction of hyperopia benefits preschool children by improving their ability to perform tasks requiring sustained, visual attention, visual motor, and visual perceptual skill.

In conclusion, these findings show a relationship between moderate, uncorrected hyperopia with reduced near visual function and deficits in measures of sustained attention, visual-motor integration and visual perception.

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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. [PubMed: 19243832]
2. Multi-Ethnic Pediatric Eye Disease Study G. 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; 117:140–7. [PubMed: 19926137]
3. Donahue SP. Prescribing Spectacles in Children: A Pediatric Ophthalmologist's Approach. *Optom Vis Sci*. 2007; 84:110–4. [PubMed: 17299340]
4. 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. [PubMed: 18326693]
5. 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. [PubMed: 19417707]
6. Simons HD, Gassler PA. Vision Anomalies and Reading Skill: A Meta-Analysis of the Literature. *Am J Optom Physiol Opt*. 1988; 65:893–904. [PubMed: 3252737]
7. 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. [PubMed: 4029521]
8. Grisham JD, Simons HD. Refractive Error and the Reading Process: A Literature Analysis. *J Am Optom Assoc*. 1986; 57:44–55. [PubMed: 3512675]
9. Kulp MT, Ciner E, et al. VIP-HIP Study Group. Uncorrected Hyperopia and Preschool Early Literacy: Results of the Vision in Preschoolers-Hyperopia in Preschoolers (VIP-HIP) Study. *Ophthalmology*. 2016; 123:681–9. [PubMed: 26826748]
10. Shankar S, Evans MA, Bobier WR. Hyperopia and Emergent Literacy of Young Children: Pilot Study. *Optom Vis Sci*. 2007; 84:1031–8. [PubMed: 18043422]
11. Atkinson J, Braddick O, Nardini M, Anker S. Infant Hyperopia: Detection, Distribution, Changes and Correlates-Outcomes from the Cambridge Infant Screening Programs. *Optom Vis Sci*. 2007; 84:84–96. [PubMed: 17299337]
12. 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. [PubMed: 12461713]
13. Roch-Levecq AC, Brody BL, Thomas RG, Brown SI. Ametropia, Preschoolers' Cognitive Abilities, and Effects of Spectacle Correction. *Arch Ophthalmol*. 2008; 126:252–8. [PubMed: 18268218]
14. Ying GS, Kulp MT, Maguire M, et al. Sensitivity of Screening Tests for Detecting Vision in Preschoolers-Targeted Vision Disorders When Specificity Is 94%. *Optom Vis Sci*. 2005; 82:432–8. [PubMed: 15894920]
15. 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. [PubMed: 11730656]
16. Roid, GH., Miller, LJ. Leiter-R Leiter International Performance Scale- Revised. Wood Dale, IL: Stoelting Co; 2002.

17. Naglieri, JA., Das, JP. Cognitive Assessment System Interpretive Handbook. Itasca, IL: Riverside; 1997.
18. Naglieri JA, Rojahn J. Construct Validity of the Pass Theory and Cas: Correlations with Achievement. *J Educ Psychol.* 2004; 96:174–81.
19. Naglieri, JA. One Hundred Years of Intelligence Testing: Moving from Traditional Iq to Second-Generation Intelligence Tests. In: Goldstein, S.Princiotta, D., Naglieri, JA., editors. *Handbook of Intelligence: Evolutionary Theory, Historical Perspective and Current Concepts.* New York: Springer; 2015. p. 295-316.
20. Beery, KE., Beery, NA. The Beery-Buktenika Developmental Test of Visual-Motor Integration Beery VMI with Supplemental Developmental Tests of Visual Perception and Motor Coordination and Stepping Stones Age Norms from Birth to Age Six Administration, Scoring, and Teaching Manual. 5. Minneapolis, MN: NCS Pearson; 2004.
21. Candy TR, Gray KH, Hohenbary CC, Lyon DW. The Accommodative Lag of the Young Hyperopic Patient. *Invest Ophthalmol Vis Sci.* 2012; 53:143–9. [PubMed: 22125280]
22. Hochberg Y, Benjamini Y. More Powerful Procedures for Multiple Significance Testing. *Stat Med.* 1990; 9:811–8. [PubMed: 2218183]
23. Cohen, J. *Statistical Power Analysis for the Behavioral Sciences.* 2. Hillsdale, NJ: L. Erlbaum Associates; 1988.
24. Mezer E, Wygnanski-Jaffe T. Do Children and Adolescents with Attention Deficit Hyperactivity Disorder Have Ocular Abnormalities? *European J Ophthalmol.* 2012; 22:931–5. [PubMed: 22505050]

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EA=Educational Assessor; EE=Eye Examiner; C= Coordinator.

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

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Table 1

Mean test scores by refractive error group.

Test	Emmetropic			Hyperopic			Unadjusted			Adjusted*			p
	Mean	SD	N=248	Mean	SD	N=244	Difference (95% Confidence Interval)	p	Difference (95% Confidence Interval)	p	Difference (95% Confidence Interval)	p	
Leiter R	35.5	(15.6)		31.3	(16.2)		-4.3 (-7.1, -1.5)	0.003	-4.1 (-6.4, -1.8)	<0.001			
CAS Receptive [‡]	15.2	(8.5)		13.9	(8.2)		-1.3 (-2.8, 0.2)	0.08	-1.1 (-2.4, 0.1)	0.08			
CAS Expressive [‡]	20.8	(13.1)		19.4	(12.5)		-1.4 (-3.7, 0.9)	0.23	-1.2 (-3.2, 0.9)	0.26			
Beery VMI	12.4	(2.5)		12.1	(2.6)		-0.4 (-0.8, 0.1)	0.11	-0.2 (-0.6, 0.1)	0.21			
Beery Visual Perception	13.8	(4.1)		13.3	(4.3)		-0.5 (-1.2, 0.3)	0.23	-0.4 (-1.1, 0.2)	0.22			

SD = standard deviation; CAS = Cognitive Assessment System; VMI = Visual-Motor Integration

* Adjusted for age at testing in months, sex, race/ethnicity, and education level of parent or caregiver.

[‡] N=244 Emmetropic and N=243 Hyperopic.

[‡] N=247 Emmetropic and N=243 Hyperopic.

Comparison of adjusted mean scores by refractive error group (most hyperopic meridian).

Table 2

Groups	Compared to	Letter R	p [*]	Adjusted [#] Mean Difference (95% Confidence Interval)						p [*]	Beery Visual Perception	p [*]
				CAS Receptive [‡]	p [*]	CAS Expressive [†]	p [*]	Beery VMI	p [*]			
Emmetropic (N=248)	Hyperopic, <4D (N=159)	-3.4 (-6.0, -0.8)	0.02	-0.3 (-1.8, 1.1)	0.66	-0.7 (-3.0, 1.6)	0.53	-0.1 (-0.5, 0.3)	0.63		-0.1 (-0.8, 0.7)	0.85
Emmetropic (N=248)	Hyperopic, 4D (N=85)	-5.3 (-8.5, -2.1)	0.004	-2.6 (-4.4, -0.8)	0.01	-2.0 (-4.8, 0.8)	0.53	-0.5 (-1.0, 0.0)	0.19		-1.1 (-2.0, -0.1)	0.08
Hyperopic, <4D (N=159)	Hyperopic, 4D (N=85)	-1.9 (-5.3, 1.6)	0.29	-2.3 (-4.2, -0.4)	0.04	-1.2 (-4.3, 1.8)	0.51	-0.4 (-0.9, 0.2)	0.35		-1.0 (-2.0, 0.0)	0.11

D = diopters; CAS = Cognitive Assessment System; VMI = Visual-Motor Integration

[#] Adjusted for age at testing in months, sex, race/ethnicity, and education level of parent or caregiver.^{*} p-values adjusted for multiple comparisons by using the Hochberg procedure.[†] N=244 Emmetropic and N=158 Hyperopic <4D.[‡] N=247 Emmetropic and N=158 Hyperopic <4D.

Table 3

Comparison of adjusted mean scores by refractive error group and accommodative lag (as measured by Grand Seiko, closest meridian).

Adjusted [#] Mean Difference (95% Confidence Interval)											
Groups	Compared to	Leiter R	p [*]	CASReceptive [‡]	p [*]	CASExpressive [‡]	p [*]	Beery VMI	p [*]	Beery Visual Perception	p [*]
Emmetropic (N=248)	Hyperopic, 1.35D lag (N=185)	-4.0 (-6.4, -1.5)	0.005	-0.2 (-1.5, 1.2)	0.79	-0.7 (-2.9, 1.4)	0.50	-0.2 (-0.6, 0.2)	0.62	-0.3 (-1.0, 0.4)	0.41
Emmetropic (N=248)	Hyperopic, >1.35D lag (N=59)	-4.6 (-8.3, -0.8)	0.03	-4.2 (-6.2, -2.1)	<0.001	-2.5 (-5.8, 0.7)	0.39	-0.3 (-0.9, 0.3)	0.62	-0.8 (-1.9, 0.3)	0.41
Hyperopic, 1.35D lag (N=185)	Hyperopic, >1.35D lag (N=59)	-0.6 (-4.5, 3.3)	0.76	-4.0 (-6.1, -1.9)	<0.001	-1.8 (-5.2, 1.6)	0.50	-0.1 (-0.7, 0.5)	0.76	-0.5 (-1.6, 0.6)	0.41

D = diopters; SD = standard deviation; CAS = Cognitive Assessment System; VMI = Visual-Motor Integration

[#]Adjusted for age at testing in months, sex, race and ethnicity, and education level of parent or caregiver.

^{*}p-values adjusted for multiple comparisons by using the Hochberg procedure.

[‡]N=244 Emmetropic and N=184 Hyperopic 1.35D lag.

[‡]N=247 Emmetropic and N=184 Hyperopic 1.35D lag.

Table 4

Comparison of adjusted mean scores by refractive error group and near visual acuity.

Adjusted [#] Mean Difference (95% Confidence Interval)											
Groups	Compared to	Letter R	[*] p	CAS Receptive [‡]	[*] p	CAS Expressive [‡]	[*] p	Beery VMI	[*] p	Beery Visual Perception	[*] p
Emmetropic (N=248)	Hyperopic better than 20/40 (N=159)	-2.9 (-5.5, -0.4)	0.05 ^{**}	-0.2 (-1.7, 1.2)	0.74	-0.2 (-2.5, 2.0)	0.85	0.0 (-0.4, 0.4)	0.99	0.0 (-0.7, 0.7)	0.99
Emmetropic (N=248)	Hyperopic 20/40 or worse (N=85)	-6.4 (-9.7, -3.2)	<0.001	-3.0 (-4.8, -1.2)	0.004	-3.1 (-6.0, -0.2)	0.10	-0.7 (-1.3, -0.2)	0.006	-1.3 (-2.2, -0.3)	0.008
Hyperopic, better than 20/40 (N=159)	Hyperopic 20/40 or worse (N=85)	-3.5 (-7.0, -0.0)	0.05 ^{**}	-2.7 (-4.6, -0.8)	0.01	-2.9 (-6.0, 0.2)	0.13	-0.7 (-1.3, -0.2)	0.01	-1.3 (-2.3, -0.3)	0.01

CAS = Cognitive Assessment System; VMI = Visual-Motor Integration

[#] Adjusted for age at testing in months, sex, race/ethnicity, and education level of parent or caregiver.^{*} p-values adjusted for multiple comparisons by using the Hochberg procedure.^{**} These p-values are both <0.05 (0.0495)[‡] N=244 Emmetropic and N=84 Hyperopic 20/40 or worse.[‡] N=247 Emmetropic and N=84 Hyperopic 20/40 or worse.

Table 5

Comparison of mean scores by refractive error group and stereoacuity.

Adjusted [#] Mean Difference (95% Confidence Interval)									
Groups	Compared to	Leiter R	p [*]	CAS Receptive [‡]	p [*]	CAS Expressive [†]	p [*]	Beery VMI	p [*] Beery Visual Perception
Emmetropic (N=248)	Hyperopic, better than 240arcsec (N=145)	-2.2 (-4.9, 0.4)	0.10	-0.4 (-1.9, 1.1)	0.61	0.3 (-2.0, 2.7)	0.77	0.1 (-0.3, 0.5)	0.73 0.4 (-0.4, 1.1)
Emmetropic (N=248)	Hyperopic, 240arcsec or worse (N=98)	-6.7 (-9.8, -3.7)	<0.001	-2.2 (-3.9, -0.5)	0.03	-3.4 (-6.1, -0.7)	0.03	-0.7 (-1.2, -0.2)	0.01 -1.7 (-2.5, -0.8)
Hyperopic, better than 240arcsec (N=145)	Hyperopic, 240arcsec or worse (N=98)	-4.5 (-7.8, -1.1)	0.02	-1.8 (-3.7, 0.0)	0.11	-3.8 (-6.7, -0.8)	0.03	-0.8 (-1.3, -0.2)	0.01 -2.0 (-3.0, -1.1)

arcsec = seconds of arc; CAS = Cognitive Assessment System; VMI = Visual-Motor Integration

[#] Adjusted for age at testing in months, sex, race/ethnicity, and education level of parent or caregiver.

^{*} p-values adjusted for multiple comparison by using the Hochberg procedure.

[†] N=244 Emmetropic and N=97 Hyperopic 240 arcsec.

[‡] N=247 Emmetropic and N=97 Hyperopic 240 arcsec.