Title
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Journal
Optometry and Vision Science, 91(4)

ISSN
1040-5488

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Publication Date
2014-04-01

DOI
10.1097/opx.0000000000000223

Peer reviewed

Published in final edited form as:
Optom Vis Sci. 2014 April ; 91(4): 383–389. doi:10.1097/OPX.0000000000000223.

Associations between Hyperopia and other Vision and Refractive Error Characteristics

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The Stereo Smile II is currently available as the Preschool Assessment of Stereopsis with a Smile (PASS) test.

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Abstract

Purpose—To investigate the association of hyperopia >+3.25D with amblyopia, strabismus, anisometropia, astigmatism, and reduced stereoacuity in preschoolers.

Methods—3- to 5-year old Head Start preschoolers (n=4040) underwent vision examination including monocular visual acuity (VA), cover testing, and cycloplegic refraction during the Vision In Preschoolers (VIP) study. VA was tested with habitual correction, and was retested with full cycloplegic correction when VA was reduced below age norms in the presence of significant refractive error. Stereoacuity testing (Stereo Smile II) was performed on 2898 children during study years 2 and 3. Hyperopia was classified into 3 levels of severity (based upon most positive meridian on cycloplegic refraction): Group 1:≥+5.00D, Group 2:>+3.25D to <+5.00D with interocular difference (IOD) in spherical equivalent (SE) ≥0.50D, and Group 3:>+3.25D to < +5.00D with IOD in SE<0.50D. “Without” hyperopia was defined as refractive error of +3.25 D or less in the most positive meridian in both eyes. Standard definitions were applied for amblyopia, strabismus, anisometropia, and astigmatism.

Results—Relative to children without hyperopia, children with hyperopia >+3.25D (N=472, Groups 1, 2, 3) had a higher proportion of amblyopia (34.5% vs. 2.8%, p<0.0001) and strabismus (17.0% vs. 2.2%, p<0.0001). More severe levels of hyperopia were associated with higher proportions of amblyopia (51.5% in Group 1 vs 13.2% in Group 3) and strabismus (32.9% in Group 1 vs 8.4% in Group 3; trend p<0.0001 for both). Presence of hyperopia >+3.25D also was associated with a higher proportion of anisometropia (26.9% vs. 5.1%, p<0.0001) and astigmatism (29.4% vs. 10.3%, p<0.0001). Median stereoacuity of non-strabismic, non-amblyopic children with hyperopia (N=206) (120″) was worse than that of children without hyperopia (60″)

(p<0.0001) and more severe levels of hyperopia were associated with worse stereoacuity (480″ for Group 1, 120″ for Groups 2 and 3, p<0.0001).

Conclusions—The presence and magnitude of hyperopia among preschoolers was associated with higher proportions of amblyopia, strabismus, anisometropia, astigmatism and with worse stereoacuity even among non-strabismic, non-amblyopic children.

Keywords

hyperopia; strabismus; amblyopia; anisometropia; astigmatism; stereoacuity

Moderate to high hyperopia is a common vision disorder in children with varying prevalence among different populations. Ying et al reported that the prevalence of hyperopia > +3.25 D in preschoolers enrolled in the Vision in Preschoolers (VIP) study varied significantly with race and ethnicity (p=0.007) from 5.5% in Asians to 6.8% in African Americans to 6.9% in Hispanics to 8.9% in American Indians to 11.9% in non-Hispanic whites.[1] A U.S. population based study of children aged 6 to < 72 months reported a prevalence in white children of 13.2% for ≥ +3 D, 5.2% for ≥ +4 D, and 2.4% for ≥ +5 D (in the more hyperopic eye).[2] The prevalence of hyperopia was also found to be lower in African-American children as compared to white or Hispanic children.[2-3] Results from a longitudinal study of school-aged children suggest that moderate to high levels of hyperopia tend to persist.[4]

Previous literature has suggested that hyperopia > +3.25 or +3.50 D is important to detect on vision screening.[5-7] Hyperopia has been reported to be associated with an increased risk of amblyopia[8] and/or strabismus.[9] Population based studies of children 6 to 72 months of age showed an association between hyperopia and esotropia (odds ratios of 23 for +3 D to < +4 D hyperopia, 59.8 for +4 to < +5 D and 122 for ≥ +5 D, reference level 0.00 to < +1 D)[10] and between bilateral hyperopia ≥ +4 D and bilateral decreased visual acuity (odds ratio of 11, reference level 0.00 to < +1 D).[11] Pascual et al recently reported that bilateral hyperopia was associated with increased odds of bilateral amblyopia in preschool children enrolled in the VIP study (odds ratio of 9.4 for bilateral hyperopia ≥ +4 D, reference level 0.00 to < +1 D, p<0.0001).[12] A recent population based study showed an increased prevalence of strabismus and amblyopia in 6- and 12-year-old children with moderate hyperopia.[13] Longitudinal studies have also supported an association between hyperopia and strabismus and/or amblyopia.[14-19] Monocular and binocular blur has been shown to decrease stereoacuity in adults[20] and an association between hyperopia and decreased stereoacuity has been reported in school aged children.[13]

Although the association between the presence and magnitude of hyperopia and amblyopia and strabismus has been well studied, the association between the presence and magnitude of hyperopia and other refractive errors (anisometropia and astigmatism) and reduced stereoacuity has not been investigated in preschool children. The Vision In Preschoolers (VIP) Study was a multicenter, cross-sectional, National Institutes of Health – National Eye Institute (NIH-NEI) funded study that evaluated the effectiveness of vision screening tests in identifying preschool children with vision disorders. The purpose of this paper is to investigate the association of hyperopia > +3.25 D (based on cycloplegic refraction) with

amblyopia, strabismus, anisometropia, astigmatism, and reduced stereoacuity in preschool children enrolled in the VIP Study.

Methods

This is a secondary data analysis of the VIP data. The VIP Study was a two phase study; Phase I identified the best tests for detection of one or more targeted vision conditions (amblyopia, strabismus, significant refractive error, and/or unexplained reduced VA) in the hands of licensed eye care practitioners and Phase II evaluated the best performing tests in the hands of trained nurse and lay screeners in schools. The details of the VIP Study methods have been published previously.[5-6] The comprehensive vision examination performed to identify vision disorders is described briefly below.

Subjects

During the VIP Study, all 3- to 5-year-old Head Start children who failed their standard school-based screening and a random sample (~20%) of those who did not fail the screening were invited to participate. All children (n=4040) underwent a comprehensive vision examination at one of 5 VIP clinical centers (New England College of Optometry, Boston, Massachusetts; Northeastern State University Oklahoma College of Optometry, Tahlequah, Oklahoma; Ohio State University College of Optometry, Columbus, Ohio; Pennsylvania College of Optometry at Salus University, Philadelphia, Pennsylvania; University of California Berkeley School of Optometry, Berkeley, California). Children with special needs were excluded. The VIP Study adhered to the tenets of the Declaration of Helsinki and was approved by the appropriate local institutional review boards associated with each VIP center. Parents or legal guardians of participating children provided written informed consent/parental permission prior to testing.

Comprehensive Vision Examination

Enrolled children received comprehensive vision examinations performed according to VIP protocol by study-certified optometrists and ophthalmologists who were experienced in providing pediatric vision care. The vision examination included monocular threshold visual acuity (VA) testing at 3 m, cover testing at distance and near, and cycloplegic refraction. VA testing was performed using single crowded HOTV optotypes on the Electronic Visual Acuity tester, according to the protocol established by the Amblyopia Treatment Study.[21] VA testing was performed with habitual correction, if any, and VA was retested with full cycloplegic correction when VA was worse than 20/50 for 3-year-olds or 20/40 for 4- to 5-year-olds or a child showed an interocular acuity difference (IOD) ≥ 2 lines; AND cycloplegic refraction showed hyperopia ≥ 2.0 D, myopia ≥ -0.5 D, or astigmatism ≥ 1.0 D in either eye. Stereoacuity testing (Stereo Smile II) was also performed on 2898 of the children during Phases I (year 2) and II with habitual correction, if any. The Stereo Smile II is a 2-alternative-forced-choice test consisting of a blank card (random dot pattern only), a non-stereo demonstration/pretest card, and four test cards (480 sec arc, 240 sec arc, 120 sec arc, and 60 sec arc at a test distance of 40 cm). Stereoacuity was the best disparity for which the child was able to obtain four correct responses (out of a maximum of five presentations at each disparity level). Children who could not complete the demonstration/ pretest card

were classified as ‘unable’. Children who were able to complete the demonstration/ pretest card, but not the 480 sec arc card were scored as having ‘no measurable stereopsis.’

Definitions of Vision Disorders

Results from the comprehensive vision examinations were used to classify children with respect to presence or absence of each type of vision disorder (Table 1). Hyperopia was defined as > +3.25 D in the most positive meridian in either eye (based upon cycloplegic refraction) and was further classified into three levels of severity. These consisted of Group 1 (≥ +5.00 D), Group 2 (> +3.25 D to < +5.00 D with interocular difference in spherical equivalent (SE) ≥ 0.50 D), and Group 3 (> +3.25 D to < +5.00 D with interocular difference in SE < 0.50 D). ‘Without’ hyperopia was defined as refractive error of +3.25 D or less in the most positive meridian in both eyes.

Unilateral amblyopia was defined as a ≥ 2-line interocular difference and presence of a unilateral amblyogenic factor (Table 1). Bilateral amblyopia was defined as presence of a bilateral amblyogenic factor along with bilaterally reduced VA (VA in the worse eye poorer than 20/50 for 3-year-olds or 20/40 for 4-year-olds and contralateral eye VA worse than 20/40 for 3-year-olds or 20/30 for 4-year-olds)(Table 1). Strabismus was defined as any heterotropia in primary gaze at distance or near. Anisometropia was defined as an interocular difference > 1 D in hyperopia, > 1.5 D in astigmatism, or > 3 D in myopia. Astigmatism was defined as > 1.5 D between principal meridians.

Statistical Analysis

For the groups of children with and without hyperopia, the proportion of each vision disorder (amblyopia, strabismus, anisometropia, and astigmatism) was calculated. The association of each vision disorder with hyperopia and with each severity level of hyperopia was assessed using the odds ratio (OR) and 95% confidence interval (95% CI) calculated from a logistic regression model. The Cochran-Armitage trend test was used to evaluate whether increasing severity of hyperopia was associated with higher proportions having each vision disorder. To evaluate whether the association of hyperopia with a vision disorder varied with the age of a child, the interaction between hyperopia and age was tested using a logistic regression model. Similar analyses were performed to evaluate the association between bilateral hyperopia with bilateral amblyopia and strabismus. The comparisons of frequency distribution of stereoacuity between eyes with versus without hyperopia and among the three severity levels of hyperopia (Groups, 1, 2, 3) were evaluated using a Fisher's exact test. Their differences in median stereoacuity were evaluated using the Wilcoxon rank sum test and Kruskal-Wallis test. All the statistical analyses were performed in SAS V9.3 (SAS Institute Inc, Cary, NC), and two-sided $p<0.05$ was considered to be statistically significant.

Results

Among the 4040 children in the VIP Study (over-represented with children with vision disorders), 472 (11.7%) had hyperopia > +3.25 D. Of these, 163 (4.0%) were in Group 1, 165 (4.1%) were in Group 2, and 144 (3.6%) were in Group 3. In addition, 264 children

(6.5%) had amblyopia, 157 (3.9%) had strabismus, 309 (7.6%) had anisometropia, and 505 (12.5%) had astigmatism.

The presence of hyperopia > +3.25 D was significantly associated with a higher proportion of children with amblyopia (34.5% vs. 2.8%, OR=18.1, p<0.0001) and strabismus (17.0% vs. 2.2%, OR=9.1, p<0.0001) (Table 2). In addition, more severe hyperopia was associated with higher proportions of amblyopia (51.5% for Group 1, 36.4% for Group 2, and 13.2% for Group 3, trend p<0.0001) and strabismus (32.9% for Group 1, 9.1% for Group 2, and 8.4% for Group 3, trend p<0.0001). Bilateral hyperopia (defined as hyperopia > +3.25D in both eyes) was also significantly associated with a higher proportion of bilateral amblyopia (23.4% vs. 4.4%, OR=6.7, p<0.0001) and strabismus (20.5% vs. 2.5%, OR=10.0, p<0.0001) (Table 3). Furthermore, increasing severity of bilateral hyperopia was associated with higher proportions of bilateral amblyopia (trend p=0.02) and strabismus (trend p<0.0001) (Table 3).

The presence of hyperopia was significantly associated with a higher proportion of anisometropia (26.9% vs. 5.1%, OR=6.8, p<0.0001) and astigmatism (29.4% vs. 10.3%, OR=3.7, p<0.0001) (Table 4). Among the 472 children with hyperopia > +3.25 D, 300 (63.6%) had either strabismus, amblyopia, astigmatism, or anisometropia.

Among these 3- to 5-year-old children, the association of hyperopia with amblyopia, strabismus, astigmatism and/or anisometropia did not vary by age (all p>0.05 for test of interaction, data not shown).

Among children without strabismus or amblyopia, the association of hyperopia with stereoacuity is presented in Table 5. The median stereoacuity of nonamblyopic, nonstrabismic children with hyperopia (N=206) was 120″, which was significantly worse than that of nonamblyopic, nonstrabismic children without hyperopia (60″) (p<0.0001) (Table 5). In addition, more severe levels of hyperopia were associated with worse stereoacuity (120″ for Groups 2 and 3, 480″ for Group 1, p=0.002) (Table 5).

Discussion

This study evaluated the association of hyperopia with various vision disorders (amblyopia, strabismus, other refractive errors and reduced stereoacuity) among a large number of preschool children (N=4040) enrolled in the Vision In Preschoolers (VIP) Study. VIP Study participants were Head Start preschool children who were geographically, racially, and ethnically diverse.[5-6] Although children were recruited to participate in the VIP Study so as to include a higher percentage of children who failed an initial screening in Head Start and were thus more likely to have vision disorders, the comparison of the proportion of vision disorders in children with and without hyperopia in the VIP population is generalizable to other hyperopic preschool children.

A population based study showed that hyperopic school-aged children were more likely to be anisometropic.[22] The VIP Study results show that hyperopic preschool children not only show a greater odds of having anisometropia, but also show an increased odds of having astigmatism as well. Therefore, preschoolers with hyperopia >+3.25 show greater odds of having other significant refractive errors.

These results show that a higher magnitude of hyperopia is associated with greater odds of amblyopia and strabismus in preschool children. While methodological differences prevent direct comparison of the risk level associated with hyperopia, these results confirm previous reports that have shown an association between hyperopia and amblyopia/visual impairment and/or strabismus.[8-19, 23] Furthermore, this study also supports previous literature showing that the association between strabismus and hyperopia is dependent on the severity of the hyperopia.[10] These findings explain in part why screening tests of refractive error can perform well in detecting amblyopia and strabismus.[5]

School-aged children with hyperopia have been shown to be more likely to have reduced stereoacuity.[13] These results extend the association between decreased stereoacuity and hyperopia to the preschool population and also show that greater magnitudes of hyperopia are associated with worse stereoacuity even among non-strabismic, non-amblyopic preschool children. Monocular or binocular blur has been associated with decreased stereoacuity.[20] While blur from uncorrected hyperopia can potentially be overcome through accommodation, children with over 4D of hyperopia have been shown to have more variable lags of accommodation suggesting a failure to accommodate accurately, at least part of the time.[24] An increased lag of accommodation results in increased hyperopic blur.

Furthermore, the hyperopic child experiences conflicting accommodative and vergence demands.[25] Uncorrected hyperopic children have a smaller convergence demand than adults (due to a smaller interpupillary distance) in the presence of a greater accommodative demand than non-hyperopes.[25] Due to the cross-link between the accommodative and vergence systems (expressed as the AC/A ratio), accurate accommodation puts the hyperopic child at risk of over-convergence and results in a need to exert sufficient divergence to maintain single vision. Thus, if a hyperopic child accommodates accurately, the child will need to compensate for this imbalance in accommodative and vergence demands through fusional divergence. Another possible means to compensate for the vergence demand is a neurological adaptation that changes the cross-link between accommodation and vergence. In fact, non-strabismic hyperopic school-aged children have been shown to have a significantly lower response AC/A ratio, suggesting a change in accommodation and vergence cross-linking, as compared to age-matched emmetropes (3.4pd/D versus 3.94pd/D).[26] However, the ability of the child to compensate for conflicting accommodation and vergence demands has been found to decrease with the magnitude of the conflict between demands.[25] Therefore, the association between decreased stereoacuity and greater magnitudes of uncorrected hyperopia may be attributed at least in part to greater difficulty compensating for the imbalance in accommodative and vergence demands as the degree of the imbalance increases. Future research should further explore the relationship between decreased stereoacuity and the presence and degree of hyperopia.

In conclusion, the presence and magnitude of hyperopia among preschoolers in the Vision in Preschoolers Study was associated with increased odds of amblyopia and strabismus and with worse stereoacuity even among non-strabismic, non-amblyopic children. Hyperopia was also associated with increased odds of anisometropia and/or astigmatism. The co-existence of hyperopia with other vision disorders should be taken into account when developing guidelines for pediatric screenings and management of refractive error. Due to

the increased odds of other vision disorders, preschool vision screenings should identify and refer children at risk for having moderate to high levels of hyperopia. Future research should further explore educational and cognitive implications of hyperopia [27-31] and the effect of early correction[18-19, 32-34] in order to increase understanding and provide optimum management guidelines for this vision disorder.

Acknowledgments

Supported by NEI/NIH, DHHS grants: U10EY12644; U10EY12547; U10EY12545; U10EY12550; U10EY12534; U10EY12647; U10EY12648 and R21EY018908.

We thank Velma Dobson, PhD, who passed away in 2010, for her invaluable contributions to the VIP Study.

References

1. Ying GS, Maguire MG, Cyert L, Ciner E, Quinn GE, Kulp MT, Orel-Bixler D, Moore B. the Vision in Preschoolers (VIP) Study Group. Prevalence of vision disorders by racial and ethnic group among children participating in Head Start. Ophthalmology. Nov 5.2013
2. Giordano L, Friedman DS, Repka MX, Katz J, Ibironke J, Hawes P, Tielsch JM. Prevalence of refractive error among preschool children in an urban population: the Baltimore Pediatric Eye Disease Study. Ophthalmology. 2009; 116:739–46. [PubMed: 19243832]
3. The Multi-Ethnic Pediatric Eye Disease Study Group. Prevalence of myopia and hyperopia in 6- to 72-month-old African American and Hispanic children. Ophthalmology. 2010; 117:140–7. [PubMed: 19926137]
4. Jones LA, Mitchell GL, Mutti DO, Hayes JR, Moeschberger ML, Zadnik K. Comparison of ocular component growth curves among refractive error groups in children. Invest Ophthalmol Vis Sci. 2005; 46:2317–27. [PubMed: 15980217]
5. Schmidt P, Maguire M, Dobson V, Quinn G, Ciner E, Cyert L, Kulp MT, Moore B, Orel-Bixler D, Redford M, Ying GS. Vision in Preschoolers Study Group. Comparison of preschool vision screening tests as administered by licensed eye care professionals in the Vision In Preschoolers Study. Ophthalmology. 2004; 111:637–50. [PubMed: 15051194]
6. Vision in Preschoolers Study Group. Preschool vision screening tests administered by nurse screeners compared with lay screeners in the vision in preschoolers study. Invest Ophthalmol Vis Sci. 2005; 46:2639–48. [PubMed: 16043831]
7. Donahue SP, Arnold RW, Ruben JB. Preschool vision screening: what should we be detecting and how should we report it? Uniform guidelines for reporting results of preschool vision screening studies. J AAPOS. 2003; 7:314–6. [PubMed: 14566312]
8. Klimek DL, Cruz OA, Scott WE, Davitt BV. Isoametropic amblyopia due to high hyperopia in children. J AAPOS. 2004; 8:310–3. [PubMed: 15314589]
9. Ingram RM. Refraction as a basis for screening children for squint and amblyopia. Br J Ophthalmol. 1977; 61:8–15. [PubMed: 836780]
10. Cotter SA, Varma R, Tarczy-Hornoch K, McKean-Cowdin R, Lin J, Wen G, Wei J, Borchert M, Azen SP, Torres M, Tielsch JM, Friedman DS, Repka MX, Katz J, Ibironke J, Giordano L. Risk factors associated with childhood strabismus: the multi-ethnic pediatric eye disease and Baltimore pediatric eye disease studies. Ophthalmology. 2011; 118:2251–61. [PubMed: 21856012]
11. Tarczy-Hornoch K, Varma R, Cotter SA, McKean-Cowdin R, Lin JH, Borchert MS, Torres M, Wen G, Azen SP, Tielsch JM, Friedman DS, Repka MX, Katz J, Ibironke J, Giordano L. Risk factors for decreased visual acuity in preschool children: the multi-ethnic pediatric eye disease and Baltimore pediatric eye disease studies. Ophthalmology. 2011; 118:2262–73. [PubMed: 21856014]
12. Pascual M, Huang J, Maguire MG, Kulp MT, Quinn GE, Ciner E, Cyert LA, Orel-Bixler D, Moore B, Ying GS. Risk Factors for Amblyopia in the Vision in Preschoolers Study. Ophthalmology. 2013

13. 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; 115:678–85. [PubMed: 17664011]
14. Dobson V, Sebris SL. Longitudinal study of acuity and stereopsis in infants with or at-risk for esotropia. Invest Ophthalmol Vis Sci. 1989; 30:1146–58. [PubMed: 2732029]
15. Ingram RM, Traynar MJ, Walker C, Wilson JM. Screening for refractive errors at age 1 year: a pilot study. Br J Ophthalmol. 1979; 63:243–50. [PubMed: 435441]
16. 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; 63:238–42. [PubMed: 435440]
17. Ingram RM, Walker C, Wilson JM, Arnold PE, Dally S. Prediction of amblyopia and squint by means of refraction at age 1 year. Br J Ophthalmol. 1986; 70:12–5. [PubMed: 3947594]
18. Atkinson J, Braddick O, Robier B, Anker S, Ehrlich D, King J, Watson P, Moore A. Two infant vision screening programmes: prediction and prevention of strabismus and amblyopia from photo- and videorefractive screening. Eye. 1996; 10(Pt 2):189–98. [PubMed: 8776448]
19. 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; 14:211–5. [PubMed: 20603055]
20. Westheimer G, McKee SP. Stereoscopic acuity with defocused and spatially filtered retinal images. J Opt Soc Am. 1980; 70:772–8.
21. Holmes JM, Beck RW, Repka MX, Leske DA, Kraker RT, Blair RC, Moke PS, Birch EE, Saunders RA, Hertle RW, Quinn GE, Simons KA, Miller JM. The amblyopia treatment study visual acuity testing protocol. Arch Ophthalmol. 2001; 119:1345–53. [PubMed: 11545641]
22. O'Donoghue L, McClelland JF, Logan NS, Rudnicka AR, Owen CG, Saunders KJ. Profile of anisometropia and aniso-astigmatism in children: prevalence and association with age, ocular biometric measures, and refractive status. Invest Ophthalmol Vis Sci. 2013; 54:602–8. [PubMed: 23233258]
23. 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; 113:1146–53. [PubMed: 16675019]
24. 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]
25. Bharadwaj SR, Candy TR. Accommodative and vergence responses to conflicting blur and disparity stimuli during development. J Vis. 2009; 9(4):1–18. [PubMed: 20053067]
26. Mutti DO, Jones LA, Moeschberger ML, Zadnik K. AC/A ratio, age, and refractive error in children. Invest Ophthalmol Vis Sci. 2000; 41:2469–78. [PubMed: 10937556]
27. Rosner J. The relationship between moderate hyperopia and academic achievement: how much plus is enough? J Am Optom Assoc. 1997; 68:648–50. [PubMed: 9354056]
28. Shankar S, Evans MA, Bobier WR. Hyperopia and emergent literacy of young children: pilot study. Optom Vis Sci. 2007; 84:1031–8. [PubMed: 18043422]
29. Simons K. Hyperopia, accommodative dysfunction and reading. Binocul Vis Strabismus Q. 2004; 19:69–70. [PubMed: 15180590]
30. Williams WR, Latif AH, Hannington L, Watkins DR. Hyperopia and educational attainment in a primary school cohort. Arch Dis Child. 2005; 90:150–3. [PubMed: 15665167]
31. Atkinson J, Anker S, Nardini M, Braddick O, Hughes C, Rae S, Wattam-Bell J, Atkinson S. Infant vision screening predicts failures on motor and cognitive tests up to school age. Strabismus. 2002; 10:187–98. [PubMed: 12461713]
32. 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]
33. Anker S, Atkinson J, Braddick O, Nardini M, Ehrlich D. Non-cycloplegic refractive screening can identify infants whose visual outcome at 4 years is improved by spectacle correction. Strabismus. 2004; 12:227–45. [PubMed: 15545141]

34. Ingram RM, Arnold PE, Dally S, Lucas J. Results of a randomised trial of treating abnormal hypermetropia from the age of 6 months. Br J Ophthalmol. 1990; 74:158–9. [PubMed: 2182103]

Hyperopia In Preschoolers

The Vision in Preschoolers Study group shows that amblyopia, strabismus, anisometropia and astigmatism are more common in preschoolers with hyperopia >3.25D and the likelihood increases as hyperopia increases. These findings may explain why screening tests of refraction perform well in detecting amblyopia and strabismus. An association between decreased stereoacuity and greater magnitudes of uncorrected hyperopia was shown even among non-strabismic, non-amblyopic children, perhaps indicating increasing difficulty compensating for accommodative and vergence demands. Due to increased odds of other vision disorders, preschool vision screenings should identify and refer children at risk for having moderate to high levels of hyperopia.

Table 1

Definitions of Vision Disorders in the Vision in Preschoolers Study.

Vision Disorder	Definitions
Hyperopia	Any hyperopia: >3.25 D in most positive meridian in either eye
	Hyperopia severity: Group 1: ≥5.0 D Group 2: >3.25D and <5.0D and interocular difference in SE of ≥0.5 D Group 3: >3.25D and <5.0D and interocular difference in SE of <0.5 D
Anisometropia	>1.00D interocular difference in hyperopia; >3.00D interocular difference in myopia; >1.50D interocular difference in astigmatism; antimetropic difference >1.00D and one eye >1.00D of hyperopia; antimetropic difference >3.00D and one eye >2.00D of myopia
Astigmatism	>1.50D between principal meridians
Unilateral Amblyopia	≥2-line interocular difference in VA and a unilateral amblyogenic factor[†]
Bilateral Amblyopia	3-year-olds : worse than 20/50 in one eye, worse than 20/40 in the contralateral eye, and a bilateral amblyogenic factor[‡]
	4- and 5-year olds: worse than 20/40 in one eye, worse than 20/30 in the contralateral eye, and a bilateral amblyogenic factor[‡]
Strabismus	Any heterotropia in primary gaze

D=diopters; VA=Visual Acuity

[†]Strabismus, anisometropia and a difference in spherical equivalent of ≥0.50D when ≥1 eye had >3.50D of hyperopia were considered unilateral amblyogenic factors.

[‡]Astigmatism of >2.50 D, hyperopia of >5.00 D, or myopia of >8.00 D in each eye were considered bilateral factors.

Table 2

Association of hyperopia with amblyopia or strabismus (N=4040).

		Amblyopia (N=264)			Strabismus (N=157)		
Hyperopia >+3.25 D (No/Yes)	**N**	**n (%)**	**OR (95% CI)**	**P***	**n (%)**	**OR (95% CI)**	**P***
No	3568	101(2.8%)	1.0		78(2.2%)	1.0	
Yes	472	163(34.5%)	18.1(13.8,23.8)	<0.0001	79(17.0%)	9.1(6.6,12.7)	<0.0001
Group 1	163	84(51.5%)	36.5(25.3,52.6)	<0.0001	52(32.9%)	21.9(14.7,32.7)	<0.0001
Group 2	165	60(36.4%)	19.6(13.5,28.5)	<0.0001	15(9.1%)	4.5(2.5,8.0)	<0.0001
Group 3	144	19(13.2%)	5.2(3.1,8.8)	<0.0001	12(8.4%)	4.1(2.2,7.7)	<0.0001
Trend p-value†		<0.0001			<0.0001		

D = Diopter; OR = Odds Ratio; CI = Confidence Interval.

*P value is from logistic regression model.

†For comparison among Groups 1, 2, 3 using Cochran-Armitage trend test.

Table 3

Association of bilateral hyperopia with bilateral amblyopia and strabismus (N=4040).

		Bilateral Amblyopia‡ (N=234)			Strabismus (N=157)		
Bilateral Hyperopia† (No/Yes)	**N§**	**n (%)**	**OR (95% CI)**	**P***	**n (%)**	**OR (95% CI)**	**P***
No	3724	162(4.4%)	1.0		94(2.5%)	1.0	
Yes	308	72(23.4%)	6.7(4.9,9.1)	<0.0001	63(20.5%)	10.0(7.1,14.1)	<0.0001
Group 1	134	40(29.9%)	9.4(6.3,14.0)	<0.0001	49(36.8%)	22.5(15.0,33.9)	<0.0001
Group 2	71	15(21.1%)	5.9(3.3,10.6)	<0.0001	7(9.9%)	4.2(1.9,9.5)	0.0005
Group 3	103	17(16.5%)	4.3(2.5,7.5)	<0.0001	7(6.8%)	2.8(1.3,6.2)	0.011
Trend p-value£		0.02			<0.0001		

D = Diopter; OR = Odds Ratio; CI = Confidence Interval.

*P value is from logistic regression model.

£For comparison among Groups 1, 2, 3 using Cochran-Armitage trend test.

†Bilateral hyperopia was defined as most positive meridian >+3.25 D in both eyes.

‡Bilateral amblyopia was defined as best-corrected VA <20/50 in each eye for 3-year-olds, best-corrected VA <20/40 in each eye for 4- to 5-year-olds.

§8 children with missing data for VA were excluded.

Table 4

Association of hyperopia with anisometropia or astigmatism (N=4040).

		Anisometropia (N=309)			Astigmatism (N=505)		
Hyperopia >+3.25 D (No/Yes)	**N**[§]	**n (%)**	**OR (95% CI)**	**P**[*]	**n (%)**	**OR (95% CI)**	**P**[*]
No	3565	182(5.1%)	1.0		366(10.3%)	1.0	
Yes	472	127(26.9%)	6.8(5.3,8.8)	<0.0001	139(29.4%)	3.7(2.9,4.6)	<0.0001
Group 1	163	44(27.0%)	6.9(4.7,10.0)	<0.0001	37(22.7%)	2.6(1.8,3.8)	<0.0001
Group 2	165	67(40.6%)	12.7(9.0,17.9)	<0.0001	44(26.7%)	3.2(2.2,4.6)	<0.0001
Group 3	144	16(11.1%)	2.3(1.4,4.0)	0.002	58(40.3%)	5.9(4.2,8.4)	<0.0001
Trend p-value[†]		0.003			0.0009		

D = Diopter; OR = Odds Ratio; CI = Confidence Interval.

[*] P value is from logistic regression models.

[†] For comparison among Groups 1, 2, 3 using Cochran-Armitage trend test.

[§] 3 children with missing data for anisometropia were excluded.

Table 5

Association of hyperopia with stereoacuity in non-strabismic, non-amblyopic children by severity level of hyperopia (N=2644)[§].

				Hyperopia > +3.25 D			
Stereoacuity Levels (arc sec)	**No Hyperopia (≤+3.25 D) (N=2338)**	**Hyperopia (>+3.25 D) (N=206)**	**P for comparing No/Yes hyperopia**	**Group 1 (N=39)**	**Group 2 (N=72)**	**Group 3 (N=95)**	**P for comparing among 3 severity levels**
Unable[£]	16 (0.7%)	6 (2.9%)	<0.0001[†]	1 (1.3%)	1 (0.9)	4 (3.8%)	0.002[†]
No measurable stereopsis	79(3.2%)	33(16.0%)		9(23.1%)	12(16.7%)	12(12.6%)	
480	95(3.9%)	23(11.2%)		11(28.2%)	7(9.7%)	5(5.3%)	
240	201(8.2%)	24(11.7%)		7(17.9%)	4(5.6%)	13(13.7%)	
120	625(25.6%)	56(27.2%)		4(10.3%)	24(33.3%)	28(29.5%)	
60	1422(58.3%)	64(31.1%)		7(17.9%)	24(33.3%)	33(34.7%)	
Median (1st, 3rd quartile)	60 (60, 120)	120 (60, 480)	<0.0001[‡]	480 (120, 480)	120 (60, 480)	120 (60, 240)	0.002[*]
P for comparing to no hyperopia				P<0.0001[‡]	P<0.0001[‡]	P<0.0001[‡]	

[†] P value is from Fisher exact test.

[‡] P value is from Wilcoxon rank sum test.

[*] P value is from Kruskal-Wallis test.

[§] Stereo acuity data is available from Phase 1 (Year 2) and Phase 2 only, and children with amblyopia or strabismus were excluded.

[£] Unable indicates child was unable to complete the demonstration/pretest card of Stereo Smile II test.