1040-5488/14/9104-0383/0 VOL. 91, NO. 4, PP. 383–389
OPTOMETRY AND VISION SCIENCE

ORIGINAL ARTICLE

Associations between Hyperopia and Other Vision and Refractive Error Characteristics

Marjean Taylor Kulp*, Gui-shuang Ying†, Jiayan Huang‡, Maureen Maguire†, Graham Quinn§, Elise B. Ciner‖, Lynn A. Cyert**, Deborah A. Orel-Bixler††, and Bruce D. Moore‖, for the VIP Study Group

ABSTRACT

Purpose. To investigate the association of hyperopia greater than +3.25 diopters (D) with amblyopia, strabismus, anisometropia, astigmatism, and reduced stereoacuity in preschoolers.

Methods. Three- to five-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 Study. Visual acuity 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 three levels of severity (based on the most positive meridian on cycloplegic refraction): group 1: greater than or equal to +5.00 D, group 2: greater than +3.25 D to less than +5.00 D with interocular difference in spherical equivalent greater than or equal to 0.50 D, and group 3: greater than +3.25 D to less than +5.00 D with interocular difference in spherical equivalent less than 0.50 D. ''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 greater than +3.25 D (n = 472, groups 1, 2, and 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). The presence of hyperopia greater than +3.25 D was also 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 nonstrabismic, nonamblyopic children with hyperopia (n = 206) (120 arcsec) was worse than that of children without hyperopia (60 arcsec) ($p < 0.0001$), and more severe levels of hyperopia were associated with worse stereoacuity (480 arcsec for group 1 and 120 arcsec for groups 2 and 3, $p < 0.0001$).

Conclusions. The presence and magnitude of hyperopia among preschoolers were associated with higher proportions of amblyopia, strabismus, anisometropia, and astigmatism and with worse stereoacuity even among nonstrabismic, nonamblyopic children.

(Optom Vis Sci 2014;91:383–389)

Key Words: hyperopia, strabismus, amblyopia, anisometropia, astigmatism, stereoacuity

*OD, MS, FAAO
†PhD
‡MS
§MD, MSCE
‖OD, FAAO
**PhD, OD, FAAO
††OD, PhD, FAAO

The Ohio State University College of Optometry, Columbus, Ohio (MTK); University of Pennsylvania, Philadelphia, Pennsylvania (G-sY, JH, MM); Children's Hospital of Pennsylvania, Philadelphia, Pennsylvania (GQ); Pennsylvania College of Optometry at Salus University, Philadelphia, Pennsylvania (EBC); Northeastern State University Oklahoma College of Optometry, Tahlequah, Oklahoma (LAC); University of California, Berkeley School of Optometry, Berkeley, California (DAO-B); New England College of Optometry, Boston, Massachusetts (BDM).

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 greater than +3.25 diopters (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 US population–based study of children aged 6 to less than 72 months reported a prevalence in white children of 13.2% for greater than or equal to +3 D, 5.2% for greater than or equal to +4 D, and 2.4% for greater than or equal to +5 D (in the more hyperopic eye).[2] The prevalence of

hyperopia was also found to be lower in African American children as compared with 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 the importance of detecting hyperopia greater than +3.25 or +3.50 D in 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 aged 6 to 72 months showed an association between hyperopia and esotropia (odds ratios [ORs] of 23 for +3 D to <+4 D, 59.8 for +4 to <+5 D, and 122 for ≥+5 D hyperopia; reference level, 0.00 to <+1 D)[10] and between bilateral hyperopia greater than or equal to +4 D and bilateral decreased visual acuity (VA; OR 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 (OR 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 VIP Study was a multicenter, cross-sectional, National Institutes of Health-National Eye Institute–funded study that evaluated the effectiveness of vision screening tests in identifying preschool children with vision disorders. The purpose of this article is to investigate the association of hyperopia greater than +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 that was 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 five VIP clinical centers (New England College of Optometry, Boston, MA; Northeastern State University Oklahoma College of Optometry, Tahlequah, OK; Ohio State University College of Optometry, Columbus, OH; Pennsylvania College of Optometry at Salus University, Philadelphia, PA; and University of California Berkeley School of Optometry, Berkeley, CA). 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 before 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 VA testing at 3 m, cover testing at distance and near, and cycloplegic refraction. Visual acuity 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] Visual acuity 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 worse than 20/40 for 4- to 5-year-olds or when a child showed an interocular acuity difference greater than or equal to two lines and cycloplegic refraction showed hyperopia greater than or equal to 2.0 D, myopia greater than or equal to −0.5 D, or astigmatism greater than or equal to 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 two-alternative forced-choice test consisting of a blank card (random dot pattern only), a nonstereo demonstration/pretest card, and four test cards (480, 240, 120, and 60 arcsec 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-arcsec 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 the presence or absence of each type of vision disorder (Table 1). Hyperopia was defined as greater than +3.25 D in the most positive meridian in either eye (based on 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 ≥0.50 D), and group 3 (>+3.25 D to <+5.00 D with interocular difference in spherical equivalent <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 greater than or equal to two-line interocular difference and presence of a unilateral amblyogenic factor (Table 1). Bilateral amblyopia was defined as

TABLE 1.
Definitions of vision disorders in the VIP Study

Vision disorder	Definitions
Hyperopia	Any hyperopia: >3.25 D in the most positive meridian in either eye Hyperopia severity: Group 1: ≥5.0 D Group 2: >3.25 D and <5.0 D and interocular difference in SE of ≥0.5 D Group 3: >3.25 D and <5.0 D and interocular difference in SE of <0.5 D
Anisometropia	>1.00 D interocular difference in hyperopia; >3.00 D interocular difference in myopia; >1.50 D interocular difference in astigmatism; antimetropic difference >1.00 D and one eye >1.00 D of hyperopia; antimetropic difference >3.00 D and one eye >2.00 D of myopia
Astigmatism	>1.50 D 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

*Strabismus, anisometropia, and a difference in SE of greater than or equal to 0.50 D when one eye or both eyes had greater than 3.50 D of hyperopia were considered unilateral amblyogenic factors.

†Astigmatism of greater than 2.50 D, hyperopia of greater than 5.00 D, or myopia of greater than 8.00 D in each eye were considered bilateral factors.

SE, spherical equivalent.

the 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 greater than 1 D in hyperopia, greater than 1.5 D in astigmatism, or greater than 3 D in myopia. Astigmatism was defined as greater than 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 OR and 95% confidence interval 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 each having 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 and without hyperopia and among the three severity levels of hyperopia (groups 1, 2, and 3) were evaluated using the Fisher 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 (overrepresented with children with vision disorders), 472 (11.7%) had hyperopia greater than +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 (6.5%) children had amblyopia, 157 (3.9%) had strabismus, 309 (7.6%) had anisometropia, and 505 (12.5%) had astigmatism.

The presence of hyperopia greater than +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 >+3.25 D 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 greater than +3.25 D, 300 (63.6%) had 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).

TABLE 2.
Association of hyperopia with amblyopia or strabismus (N = 4040)

Hyperopia >+3.25 D (no/yes)	N	Amblyopia (n = 264)			Strabismus (n = 157)		
		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†		<0.0001			<0.0001		

*p value is from a logistic regression model.
†For comparison among groups 1, 2, and 3 using the Cochran-Armitage trend test.
CI, confidence interval.

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 arcsec, which was significantly worse than that of nonamblyopic, nonstrabismic children without hyperopia (60 arcsec) ($p < 0.0001$) (Table 5). In addition, more severe levels of hyperopia were associated with worse stereoacuity (120 arcsec for groups 2 and 3 and 480 arcsec 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 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 greater odds of having anisometropia but also show increased odds of having astigmatism. Therefore, preschoolers with hyperopia greater than +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. Although 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 nonstrabismic, nonamblyopic preschool children. Monocular or

TABLE 3.
Association of bilateral hyperopia with bilateral amblyopia and strabismus (N = 4040)

Bilateral hyperopia* (no/yes)	N†	Bilateral amblyopia‡ (n = 234)			Strabismus (n = 157)		
		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‖		0.02			<0.0001		

*Bilateral hyperopia was defined as the most positive meridian greater than +3.25 D in both eyes.
†Eight children with missing data for VA were excluded.
‡Bilateral amblyopia was defined as best-corrected VA <20/50 in each eye for 3-year-olds and best-corrected VA <20/40 in each eye for 4- to 5-year-olds.
§p value is from a logistic regression model.
‖For comparison among groups 1, 2, and 3 using the Cochran-Armitage trend test.
CI, confidence interval.

TABLE 4.

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

Hyperopia >+3.25 D (no/yes)	N*	Anisometropia (n = 309)			Astigmatism (n = 505)		
		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‡		0.003			0.0009		

*Three children with missing data for anisometropia were excluded.
†p value is from logistic regression models.
‡For comparison among groups 1, 2, and 3 using the Cochran-Armitage trend test.
CI, confidence interval.

binocular blur has been associated with decreased stereoacuity.[20] Although blur from uncorrected hyperopia can potentially be overcome through accommodation, children with over 4 D 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 (owing to a smaller interpupillary distance) in the presence of a greater accommodative demand than nonhyperopes.[25] Because of the cross-link between the accommodative and vergence systems (expressed as the AC/A ratio), accurate accommodation puts the hyperopic child at risk of overconvergence 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, nonstrabismic, 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 with age-matched emmetropes (3.4 vs. 3.94 pd/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 VIP Study were associated with increased odds of amblyopia and strabismus and with worse stereoacuity even among nonstrabismic, nonamblyopic children. Hyperopia was also associated with increased odds of anisometropia and/or astigmatism. The coexistence of hyperopia with other vision disorders

TABLE 5.

Association of hyperopia with stereoacuity in nonstrabismic, nonamblyopic children by severity level of hyperopia (n = 2644)

Stereoacuity levels (arcsec)	No hyperopia (≤+3.25 D) (n = 2338)	Hyperopia (>+3.25 D) (n = 206)	p for comparing no/yes hyperopia	Hyperopia >+3.25 D			p for comparing among three severity levels
				Group 1 (n = 39)	Group 2 (n = 72)	Group 3 (n = 95)	
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 (first, third 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				<0.0001‡	<0.0001‡	<0.0001‡	

Stereoacuity data are available from phase I (year 2) and phase II only, and children with amblyopia or strabismus were excluded. With the exception of median and p values, data are expressed as number (percentage).
*Unable indicates child was unable to complete the demonstration/pretest card of the Stereo Smile II test.
†p value is from the Fisher exact test.
‡p value is from the Wilcoxon rank sum test.
§p value is from the Kruskal-Wallis test.

should be taken into account when developing guidelines for pediatric screenings and management of refractive error. Because of 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

The VIP Study Group

Executive Committee

Paulette Schmidt, OD, MS (Chair); Agnieshka Baumritter, MA; Elise Ciner, OD; Lynn Cyert, PhD, OD; Velma Dobson, PhD; Beth Haas; Marjean Taylor Kulp, OD, MS; Maureen Maguire, PhD; Bruce Moore, OD; Deborah Orel-Bixler, PhD, OD; Ellen Peskin, MA; Graham Quinn, MD, MSCE; Maryann Redford, DDS, MPH; Janet Schultz, RN, MA, CPNP; and Gui-shuang Ying, PhD.

Participating Centers

AA, Administrative Assistant; BPC, Back-up Project Coordinator; GSE, Gold Standard Examiner for comprehensive vision examinations; LS, Lay Screener; NS, Nurse Screener; PI, Principal Investigator; PC, Project Coordinator; PL, Parent Liaison; PR, Programmer; VD, Van Driver; and NHC, Nurse/Health Coordinator.

Berkeley, CA: University of California Berkeley School of Optometry: Deborah Orel-Bixler, PhD, OD (PI/GSE); Pamela Qualley, MA (PC); Dru Howard (BPC/PL); Lempi Miller Suzuki (BPC); Sarah Fisher, PhD, OD (GSE); Darlene Fong, OD (GSE); Sara Frane, OD (GSE); Cindy Hsiao-Threlkeld, OD (GSE); Selim Koseoglu, MD (GSE); A. Mika Moy, OD (GSE); Sharyn Shapiro, OD (GSE); Lisa Verdon, OD (GSE); Tonya Watson, OD (GSE); Sean McDonnell (LS/VD); Erika Paez (LS); Darlene Sloan (LS); Evelyn Smith (LS); Leticia Soto (LS); Robert Prinz (LS); Joan Edelstein, RN (NS); and Beatrice Moe, RN (NS).

Boston, MA: New England College of Optometry: Bruce Moore, OD (PI/GSE); Joanne Bolden (PC); Sandra Umaña (PC/LS/PL); Amy Silbert (BPC); Nicole Quinn, OD (GSE); Heather Bordeau, OD (GSE); Nancy Carlson, OD (GSE); Amy Croteau, OD (GSE); Micki Flynn, OD (GSE); Barry Kran, OD (GSE); Jean Ramsey, MD (GSE); Melissa Suckow, OD (GSE); Erik Weissberg, OD (GSE); Marthedala Chery (LS/PL); Maria Diaz (LS); Leticia Gonzalez (LS/PL); Edward Braverman (LS/VD); Rosalyn Johnson (LS/PL); Charlene Henderson (LS/PL); Maria Bonila (PL); Cathy Doherty, RN (NS); Cynthia Peace-Pierre, RN (NS); Ann Saxbe, RN (NS); and Vadra Tabb, RN (NS).

Columbus, OH: The Ohio State University College of Optometry: Paulette Schmidt OD, MS (PI); Marjean Taylor Kulp, OD, MS (Co-Investigator/GSE); Molly Biddle, MA (PC); Jason Hudson (BPC); Melanie Ackerman, OD (GSE); Sandra Anderson, OD (GSE); Michael Earley, OD, PhD (GSE); Kristyne Edwards, OD, MS (GSE); Nancy Evans, OD (GSE); Heather Gebhart, OD (GSE); Jay Henry, OD, MS (GSE); Richard Hertle, MD (GSE); Ann Hickson, OD, MS (GSE/LPS); Jeffrey Hutchinson, DO (GSE); LeVelle Jenkins, OD (GSE); Andrew Toole, OD, MS (GSE); Keith Johnson (LS/VD); Richard Shoemaker (VD); Rita Atkinson (LS); Fran Hochstedler (LS); Tonya James (LS); Tasha Jones (LS); June Kellum (LS); Denise Martin (LS); Christina Dunagan, RN (NS); Joy Cline, RN (NS); and Sue Rund, RN (NS).

Philadelphia, PA: Pennsylvania College of Optometry: Elise Ciner, OD (PI/GSE); Angela Duson (PC/LS); Lydia Parke (BPC); Mark Boas, OD (GSE); Shannon Burgess, OD (GSE); Penelope Copenhaven, OD (GSE); Ellie Francis, PhD, OD (GSE); Michael Gallaway, OD (GSE); Sheryl Menacker, MD (GSE); Graham Quinn, MD, MSCE (GSE); Janet Schwartz, OD (GSE); Brandy Scombordi-Raghu, OD (GSE); Janet Swiatocha, OD (GSE); Edward Zikoski, OD (GSE); Jennifer Lin, MD (GSE); Leslie Kennedy (LS/PL); Rosemary Little (LS/PL); Geneva Moss (LS/PL); Latricia Rorie (LS); Shirley Stokes (LS/PL); Jose Figueroa (LS/VD); Eric Nesmith (LS); Gwen Gold (BPC/NHC/PL); Ashanti Carter (PL); David Harvey (LS/VD); Sandra Hall, RN (NS); Lisa Hildebrand, RN (NS); Margaret Lapsley, RN (NS); Cecilia Quenzer, RN (NS); and Lynn Rosenbach, RN (NHC/NS).

Tahlequah, OK: Northeastern State University College of Optometry: Lynn Cyert, PhD, OD (PI/GSE); Linda Cheatham (PC/VD); Anna Chambless (BPC/PL); Colby Beats, OD (GSE); Jerry Carter, OD (GSE); Debbie Coy, OD (GSE); Jeffrey Long, OD (GSE); Shelly Rice, OD (GSE); Shelly Dreadfulwater, (LS/PL); Cindy McCully (LS/PL); Rod Wyers (LS/VD); Ramona Blake (LS/PL); Jamey Boswell (LS/PL); Anna Brown (LS/PL); Jeff Fisher, RN (NS); and Jody Larrison, RN (NS).

Study Center

Columbus, OH: The Ohio State University College of Optometry: Paulette Schmidt, OD, MS (PI) and Beth Haas (Study Coordinator).

Coordinating Center

Philadelphia, PA: University of Pennsylvania, Department of Ophthalmology: Maureen Maguire, PhD (PI); Agnieshka Baumritter, MA (Project Director); Mary Brightwell-Arnold (Systems Analyst); Christine Holmes (AA); Andrew James (PR); Aleksandr Khvatov (PR); Lori O'Brien (AA); Ellen Peskin, MA (Project Director); Claressa Whearry (AA); and Gui-shuang Ying, PhD (Biostatistician).

Advisory Committee (voting members)

Roy Beck (Chair), Susan Cotter, Jonathan Holmes, Melvin Shipp, and Sheila West.

National Eye Institute

Bethesda, MD: Maryann Redford, DDS, MPH.

Supported by National Eye Institute/National Institutes of Health, Department of Health and Human Services grants: U10EY12644, U10EY12547, U10EY12545, U10EY12550, U10EY12534, U10EY12647, U10EY12648, and R21EY018908.

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

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

The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

Received September 22, 2013; accepted January 9, 2014.

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Marjean Taylor Kulp
The Ohio State University College of Optometry
338 W Tenth Ave
Columbus, OH 43210
e-mail: kulp.6@osu.edu