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Br J Ophthalmol 2010 94: 542-546 originally published online October 22, 2009

doi: 10.1136/bjo.2009.163709

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Prevalence of heterophoria and associations with refractive error, heterotropia and ethnicity in Australian school children

Jody F Leone,¹ Elaine Cornell,¹ Ian G Morgan,² Paul Mitchell,³ Annette Kifley,³ Jie Jin Wang,³ Kathryn A Rose¹

¹Discipline of Orthoptics, Faculty of Health Sciences, University of Sydney, Sydney, Australia

²ARC Centre of Excellence in Vision Science, School of Biology, The Australian National University, Canberra, Australia

³Department of Ophthalmology (Centre for Vision Research, Westmead Millennium Institute, Westmead Hospital), University of Sydney, Westmead, Australia

Correspondence to

Dr Kathryn A Rose, Discipline of Orthoptics, Faculty of Health Sciences, University of Sydney (Cumberland Campus), PO Box 170, Lidcombe NSW 1825, Australia; k.rose@usyd.edu.au

Accepted 1 October 2009

Published Online First

22 October 2009

ABSTRACT

Aims To establish the prevalence of heterophoria and its association with refractive error and ethnicity in a population-based study of Australian schoolchildren.

Methods The Sydney Myopia Study is a stratified, random cluster (school-based) sample of 4093 students (examined: 2003–2005). Two samples aged 6 (n=1692) and 12 years (n=2289) without heterotropia were included. Prevalent heterophoria was assessed using cover un-cover and prism bar alternate cover testing at 33 cm and 6 m distance fixation. Cycloplegic autorefractometry (1% cyclopentolate) was performed. Significant refractive error was defined as ≤ -0.50 SE and $\geq +2.00$ SE.

Results Exophoria was highly prevalent at near fixation (age 6: 58.3%, age 12: 52.2%). Orthophoria predominated at distance fixation (age 6: 85.4%, age 12: 90.9%). Hyperopia was associated with esophoria at near (age 6: OR 1.7, 95% CI 1.1 to 2.8, age 12: OR 2.9, CI 1.1 to 2.8) and distance fixation (age 6: OR 9.7, CI 3.5 to 26, age 12: 9.6 OR, CI 4.2 to 22). Myopia was associated with exophoria at near (OR 2.1, CI 1.5 to 2.7) and distance fixation (OR 3.1, CI 2.1 to 4.4) for 12-year-old children only. Exophoria was more frequent in children of East Asian than European Caucasian origins, even after adjusting for refraction; at near (age 6: OR 1.4, CI 1.0 to 2.0, age 12: OR 1.4, CI 1.0 to 1.9) and distance (age 12: OR 1.7, CI 1.1 to 2.7).

Conclusion Contrary to other studies, exophoria, not orthophoria, was predominant for near. Exophoria was more prevalent in children of East Asian origin. Longitudinal studies are needed to establish if incident heterotropia is preceded by heterophoria.

Heterophoria is a latent deviation of the eyes that is only revealed when fusional vergence is disrupted, allowing the eyes to assume their position of rest.¹ Upon resumption of binocular viewing, fusional vergence is used to return the eyes to alignment. Heterophoria is categorised by the direction of movement of the eyes when they are dissociated; esophoria describes an inward horizontal movement, while exophoria is an outward movement. Orthophoria is the absence of any movement on dissociation. Dissociative vertical movements of the eyes, either upwards (hyperphoria) or downwards (hypophoria) are infrequent, but can sometimes occur in combination with horizontal heterophorias.

While heterophoria is generally without symptoms, poorly controlled heterophoria may lead to symptoms such as headache, blurred vision,

diplopia or confusion, with the possibility of a manifest intermittent heterotropia.¹ Failure to compensate for a heterophoria will result in a heterotropia, but the failure of compensation does not depend on the size of the heterophoria, but rather on inadequate fusional reserves.

There have been differences in the reported prevalence^{2–8} and distribution of heterophoria at near.^{3 4 9} However, previous studies of children are in agreement that orthophoria predominates at distance fixation,^{2 3 5} with a relatively tight (leptokurtic) distribution.^{3 4 9 10} Heterophoria prevalence has been reported for European Caucasian populations,^{2–5} but there are no reports for East Asian samples. Factors reported to be associated with heterophoria include age^{2 3 7} and gender.¹¹ While a relationship between heterophoria and refractive error has often been claimed,^{12 13} studies specifically investigating this link have reported no association,⁴ or no direct relationship between the amount of ametropia and heterophoria.¹¹ In this paper, we aim to document the prevalence of heterophoria and its subtypes in a large school-based sample of Australian school-aged children and to examine its associations.

MATERIALS AND METHODS

The Sydney Myopia Study was a school-based, cross-sectional, survey of refraction and eye health in 4093 Sydney schoolchildren during 2003–2005. Detailed study methods have been described elsewhere.¹⁴ Schools were randomly selected using a stratified cluster sampling design.

All tests of ocular alignment were performed by orthoptists. Corneal reflections (Hirschberg test) were observed, followed by a cover/uncover test. Children with manifest heterotropia were excluded from analysis. In all other children, a slow alternate cover test (using a Clement Clarke occluder, Haag-Streit, UK) was performed to fully dissociate the eyes and reveal any heterophoria. At 33 cm, the Clement Clark fixation stick, with standardised detailed targets was used. Initially, the target was briefly moved sideways to ensure uniocular fixation. To ensure accommodation, younger children were asked to describe detail of the picture target while older children read the reduced Snellen's optotypes. At 6 m, a detailed picture was used. If a child wore glasses, both the prevalent heterophoria (without glasses) and the presenting heterophoria (with habitual glasses worn) were assessed. Heterophoria size was measured using the alternate

prism cover test¹⁵ using Luneau prism bars in 2 prism dioptre (PD) steps, and classified as ≥ 2 PD of esophoria, exophoria or hyperphoria. Orthophoria was defined as a heterophoria between > -2 PD and < 2 PD. In this study, prevalent heterophoria was analysed unless specified otherwise. Heterophoria assessment was not performed using best-corrected glasses, as this would induce a short-term change in heterophoria.^{1 16}

Cycloplegic autorefraction was performed on all children (RK-F1 Auto Ref-Keratometer; Canon, Tokyo, Japan) using amethocaine (0.5%) instilled 2 min prior to one drop each of cyclopentolate (1%) and tropicamide (1%) and repeated after 5 min. Autorefraction was performed an average of 25 min after the instillation of the last drops. Cycloplegia was assessed by pupil diameter ≥ 6 mm and no reaction to light or accommodative target. Clinically significant refractive error was defined for myopia as ≤ -0.50 SE and for hyperopia if spherical equivalent refraction was $\geq +2.00$ SE.

Data were entered into a Microsoft Access database (Microsoft). All statistical analysis was performed using SAS software, version 8.2 (SAS Institute, Cary, North Carolina). The proportion of children with orthophoria, exophoria and esophoria was adjusted for cluster by schools. These rates are compared between age samples and demographic subgroups using χ^2 tests for independence. Among children with heterophoria, mean PD of heterophoria were compared between age samples using two-sample t tests. Polytomous logistic regression with a generalised logit link was used to compare the odds of having heterophoria between children in different refractive and demographic subgroups. All ORs are unadjusted unless otherwise stated. In these analyses, orthophoria was used as the reference response category.

Approval for the study was obtained from the Human Research Ethics Committee, University of Sydney; the Department of Education and Training in New South Wales; Catholic Education Office and private schools. The study adhered to the tenets of the declaration of Helsinki. Informed written consent from at least one parent and verbal assent from each child were obtained prior to examination.

RESULTS

Two age cohorts, 1740 students in year 1 (mean age 6.7 years, age range 5.5–8.1 years, SD 0.42 years) and 2353 students in year 7 (mean age 12.7 years, age range 11.1–14.4 years, SD 0.44 years), were examined, with response rates among eligible 6- and 12-year-old children of 77.6% and 75.3%, respectively. Among the children included in this study, 50.7% of the 6-year-old children were boys, as were 50.8% of the 12-year-old children. Most children were of European Caucasian (63.4% of the 6-year-old-children and 60.0% of the 12-year-old-children) or East Asian ethnicity (17.3% of the 6-year-old-children and 14.9% of the 12-year-old children). Other ethnic groups were too small to permit meaningful analysis. Of 1740 children aged 6 years, we excluded 48 (2.8%) children with heterotropia, of whom 26 had esotropia, 14 had exotropia, seven had microtropia, and one had VIth cranial nerve palsy.¹⁷ Of 2353 children aged 12 years, we excluded a similar proportion of children with heterotropia (2.7% $n=64$), of whom 21 had had esotropia, 27 had exotropia, and 16 had a microtropia.¹⁸

Prevalence of heterophoria

Figure 1 shows the prevalence of heterophoria for the two age groups for near and distance fixation. At near fixation, exophoria was the most frequently occurring prevalent heterophoria (ie, without glasses), present in 58.3% of the 6-year-old and 52.2% of

the 12-year-old children. At distance fixation, 85.4% of the 6-year-old and 90.9% of the 12-year-old children were orthophoric. Esophoria was rare at distance fixation (1.0%, 1.3% for ages 6 and 12 respectively) and had a low prevalence at near fixation (9.2%, 10.4% for ages 6 and 12 respectively); see figure 1. There was a trend towards an increasing proportion of orthophoria in the older age group, and significantly less exophoria in the older age group (7.8%) compared with the younger age group (13.5%), at distance fixation ($p=0.007$) (figure 1). There was no significant difference found between the age groups in the other forms of heterophoria at either distance. Vertical heterophoria was detected in a small number of children at both near ($n=9$, 0.2%) and distance ($n=4$, 0.1%), mostly coexisting with a horizontal heterophoria. There were no significant gender differences in heterophoria, apart from 6-year old girls having more exophoria at near fixation (OR 1.4, 95% CI 1.1 to 1.7).

Size of prevalent heterophoria

Figure 2 shows the distribution of heterophoria for the two age groups for near and distance fixation. A Kolmogorov–Smirnov goodness-of-fit test showed that the size (measured in PD) of horizontal prevalent heterophoria at both distances and in both age groups was not normally distributed ($p<0.0001$). The distribution of near heterophoria for both age groups was mildly leptokurtic and skewed towards exophoria (kurtosis: 1.6 in children aged 6 years and 5.3 in children aged 12 years). Distance heterophoria was markedly leptokurtic and mildly skewed towards exophoria for both age groups (kurtosis: 20.2 in children aged 6 years and 38.5 in children aged 12 years) (figure 2).

The average magnitude of prevalent heterophoria at near fixation was lower in the 12-year-old (exophoria: 3.9 PD; esophoria: 3.8 PD) than in the 6-year-old children (exophoria: 4.9 PD, $p<0.0001$; esophoria: 4.4 PD, $p=0.01$). However, the difference was not clinically significant, at only around 1 PD. There was no significant age difference in prevalent heterophoria size noted for distance fixation.

Large prevalent heterophoria

A small number of children, 82 (4.9%) aged 6, and 74 (3.2%) aged 12, had a large prevalent heterophoria (ie, ≥ 10 PD, maximum

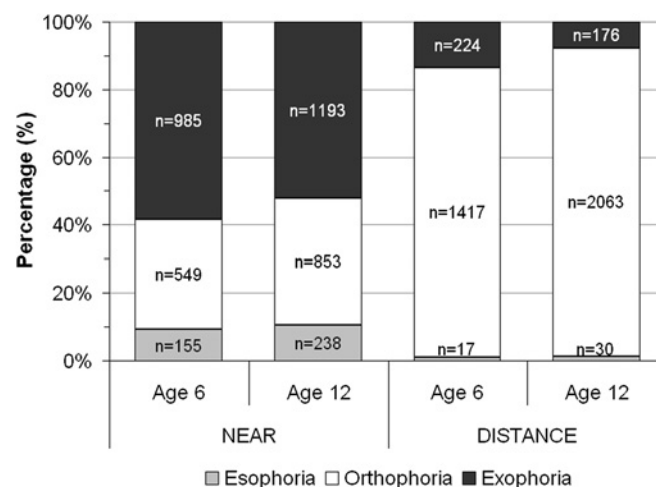


Figure 1 Percentage of different types of prevalent heterophoria (without glasses) in children aged 6 and 12 years, at near and at distance. Significant differences, when comparing percentages between the two age groups, occurred only at distance fixation for orthophoria ($p=0.01$) and for exophoria ($p=0.007$).

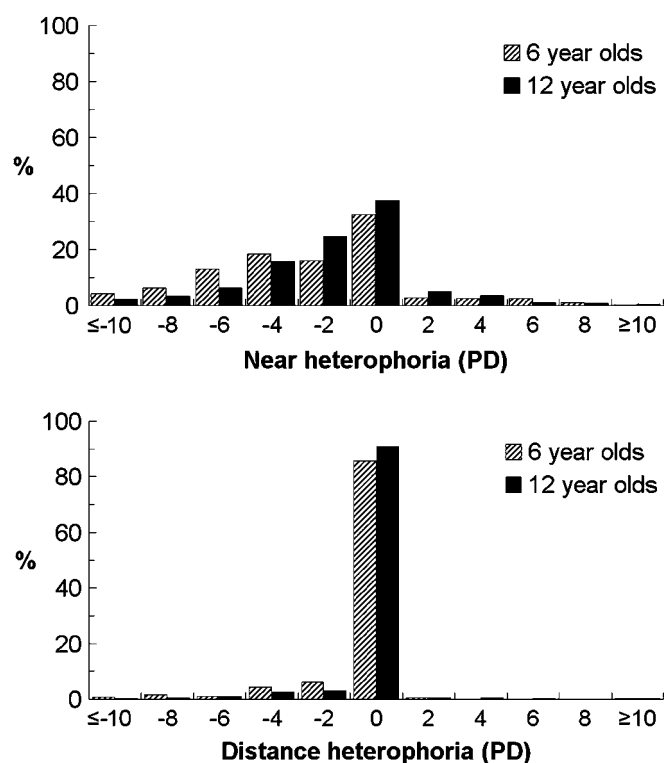


Figure 2 Bar graphs demonstrating the distribution of prevalent heterophoria (measured at near and distance fixation) in prism dioptres (PD) for all children aged 6 and 12 years (negative values indicate exophoria, and positive values indicate esophoria).

25 PD), usually at near (80.7% of cases aged 6 and 85.1% aged 12 years). The remainder were either at distance only (8.4% of cases aged 6 and 6.8% aged 12 years) or at both near and distance fixation (10.8% of cases aged 6 and 8.1% aged 12 years). In children with large heterophoria aged 12, 45.6% had a significant refractive error in comparison with 17.4% of those without large

heterophoria ($p < 0.0001$). However, in children with large heterophoria aged 6, the proportion with refractive error was not significantly different (19% with large heterophoria, 13.4% without, $p = 0.16$).

Relationship between prevalent heterophoria, refractive error and ethnicity

The proportion of children aged 6 with hyperopia was 12.1%, and myopia 1.4%. In the children aged 12, the proportion with hyperopia was lower (4.3%), but myopia was higher (12.3%). Table 1 shows the association between heterophoria and refractive error for the two age groups. Significant associations were found between cycloplegic refractive error and prevalent heterophoria (measured without glasses), for both near (6-year-old children: $p = 0.03$; 12-year-old children: $p < 0.0001$) and distance fixation (both age groups: $p < 0.0001$). While esophoria was rare, children with hyperopia were significantly more likely than those without refractive error to have esophoria at near (age 6: OR 1.7; age 12: OR 2.9) and distance (age 6: OR 9.7; age 12: OR 9.6) (table 1). The proportion of children with myopia and esophoria at near was less than 1% of the total sample, and 8.6% of the myopic population. In the older children, those with myopia were significantly more likely than those without refractive error to be exophoric at near and distance (table 1). This association was not evident in the younger children, in whom very few had myopia.

Table 2 shows the prevalence of heterophoria by ethnicity for the two age groups. East Asian children were significantly more likely than European Caucasian children to be exophoric at near, in both 6-year (OR 1.4, 95% CI 1.1 to 1.9) and 12-year groups (OR 1.8, 95% CI 1.5 to 2.5), and at distance in the 12-year group (OR 2.7, 95% CI 1.9 to 4.1) (table 2). After adjusting for refractive error, gender and age, these ethnicity associations with exophoria at near remained significant for both children aged 6 years (adjusted OR 1.4, 95% CI 1.0 to 2.0) and 12 years (adjusted OR 1.4, 95% CI 1.0 to 1.9), and the association with exophoria at distance remained significant for the 12-year-old

Table 1 Number, proportion and ORs for prevalent heterophoria (without glasses) among children aged 6 and 12 years with different refractive status by myopia and hyperopia

	At near					At distance				
	Orthophoria reference group	Esophoria	OR (95% CI)	Exophoria	OR (95% CI)	Orthophoria reference group	Esophoria	OR (95% CI)	Exophoria	OR (95% CI)
	n (%)	n (%)		n (%)		n (%)	n (%)		n (%)	
Age 6										
No significant refractive error*	474 (33)	122 (8)	1.0	852 (59)	1.0	1224 (86)	7 (0.5)	1.0	192 (13.5)	1.0
Myopia†	5 (21)	1 (4)	0.8 (0.1 to 6.7)	18 (75)	2.0 (0.7 to 5.4)	20 (91)	0 (—)	—	2 (9)	—
Hyperopia‡	66 (33)	29 (14)	1.7 (1.1 to 2.8)§	107 (53)	0.9 (0.6 to 1.3)	163 (82)	9 (5)	9.7 (3.5 to 26)§	26 (13)	1.0 (0.6 to 1.6)
	Overall p for association = 0.03					Overall p for association < 0.0001				
Age 12										
No significant refractive error*	742 (39)	195 (10)	1.0	961 (51)	1.0	1743 (93)	20 (1)	1.0	120 (6)	1.0
Myopia†	72 (26)	13 (5)	0.7 (0.4 to 1.3)	192 (69)	2.1 (1.5 to 2.7)¶	228 (83)	0 (—)	—	48 (17)	3.1 (2.1 to 4.4)¶
Hyperopia‡	36 (37)	27 (28)	2.9 (1.7 to 4.8)§	34 (35)	0.7 (0.4 to 1.2)	82 (84)	9 (9)	9.6 (4.2 to 22)§	7 (7)	1.2 (0.6 to 2.7)
	Overall p for association < 0.0001					Overall p for association < 0.0001				

*No significant refractive error defined as spherical equivalent > -0.5 SE to $< +2.0$ SE.

†Myopia defined as: spherical equivalent ≤ -0.5 SE.

‡Hyperopia defined as: spherical equivalent $\geq +2.0$ SE.

§The odds of esophoria rather than orthophoria was significantly increased in those with hyperopia compared with those with no significant refractive error.

¶The odds of exophoria rather than orthophoria was significantly increased in those with myopia compared with those with no significant refractive error.

Table 2 Prevalent heterophoria (without glasses) prevalence in children aged 6 and 12 years attending the Sydney Myopia Study, by ethnicity

	Esophoria			Exophoria			Orthophoria reference group	
	n	Percentage (95% CI*)	p Value†	n	Percentage (95% CI*)	p Value†	n	Percentage (95% CI*)
At near								
Age 6								
European Caucasian	119	11.1 (8.8 to 13.4)		592	55.3 (50.9 to 59.8)		359	33.6 (29.1 to 38.0)
East Asian	8	2.7 (1.1 to 4.4)	0.001	200	68.5 (63.6 to 73.4)	0.01	84	28.8 (24.3 to 33.2)
Age 12								
European Caucasian	166	12.2 (10.5 to 13.8)		651	47.7 (40.7 to 54.6)		549	40.2 (33.0 to 47.4)
East Asian	17	5.0 (3.5 to 6.6)	0.04	221	65.6 (56.9 to 74.3)	<0.0001	99	29.4 (20.9 to 37.9)
At distance								
Age 6								
European Caucasian	16	1.5 (0.7 to 2.3)		131	12.4 (9.4 to 15.3)		913	86.1 (83.1 to 89.0)
East Asian	1	0.4 (0.0 to 0.9)	0.2	55	19.6 (14.1 to 25.0)	0.003	225	80.1 (74.6 to 85.6)
Age 12								
European Caucasian	21	1.6 (1.0 to 2.1)		74	5.5 (3.0 to 7.9)		1263	93.0 (90.3 to 95.7)
East Asian	2	0.6 (0.0 to 1.4)	0.2	46	13.8 (7.2 to 20.3)	<0.0001	286	85.6 (78.6 to 92.6)

*CIs adjusted for cluster sampling.

†p Values compare the likelihood of esophoria or exophoria rather than orthophoria when comparing children of East Asian ethnicity with children of European Caucasian ethnicity. For esophoria at distance, numbers were too small for a meaningful statistical comparison.

group (adjusted OR 1.7, 95% CI 1.1 to 2.7). The average inter-pupillary distance (IPD) in European Caucasian and East Asian children was not significantly different at age 6 years (56.2 mm, 56 mm respectively, $p=0.4$). While the average IPD in children aged 12 years is larger, there was still no significant difference between European Caucasian (59.7 mm) and East Asian children (60.1 mm) ($p=0.7$).

Impact of habitual glasses on the measurement of heterophoria

There were 35 children aged 6 years and 300 children aged 12 years who wore glasses habitually. Of those who had a small heterophoria (<10 PD) (30 aged 6, 269 aged 12), only a small proportion had a substantial change (>4 PD) in heterophoria size with their glasses (6.7% age 6 and 10.4% age 12). However, for those who had a large heterophoria (≥ 10 PD) (five aged 6, 31 aged 12) this proportion was much higher (two aged 6 (40%), 13 aged 12 (41.9%)). In most cases, the change with glasses diminished the size of the heterophoria (85% age 6 and age 12). However, seven children developed a significantly larger heterophoria (>4 PD) when wearing their glasses. In all cases, the glasses worn were not appropriate for the direction of their prevalent heterophoria, three became more exophoric when wearing their hyperopic prescription, and four became more esophoric when wearing their myopic prescription.

Heterophoria and heterotropia

Figure 3 compares the proportions of heterophoria with heterotropia for the two age groups. Sixty-two children were found to have heterotropia on cover test examination. While esophoria was uncommon for both age groups, esotropia was the predominant heterotropia, particularly for constant heterotropias. For intermittent heterotropias, the proportion of esotropia was lower (6 years 35%, 12 years 25.7%), and more closely resembled the proportion of esophoria for both near (6 years 13.6%, 12 years 16.6%) and distance (6 years 7% and 12 years 14.6%). However, in absolute numbers, the number of children with detectable heterophoria was much higher than the number of those with heterotropia (figure 3).

DISCUSSION

Consistent with other studies, we found that orthophoria was the main phoric state at distance fixation^{2 3 5 8} and the distri-

bution of heterophoria size was leptokurtic.^{3 9 19 20} In our population, the distribution was skewed towards exophoria in both the 6- and 12-year-old children. This was true for both major ethnic groups in the sample—European Caucasian and East Asian. This tight distribution of heterophoria at distance around orthophoria suggests an active biological process of orthophorisation, as previously postulated.^{3 19} This is likely to

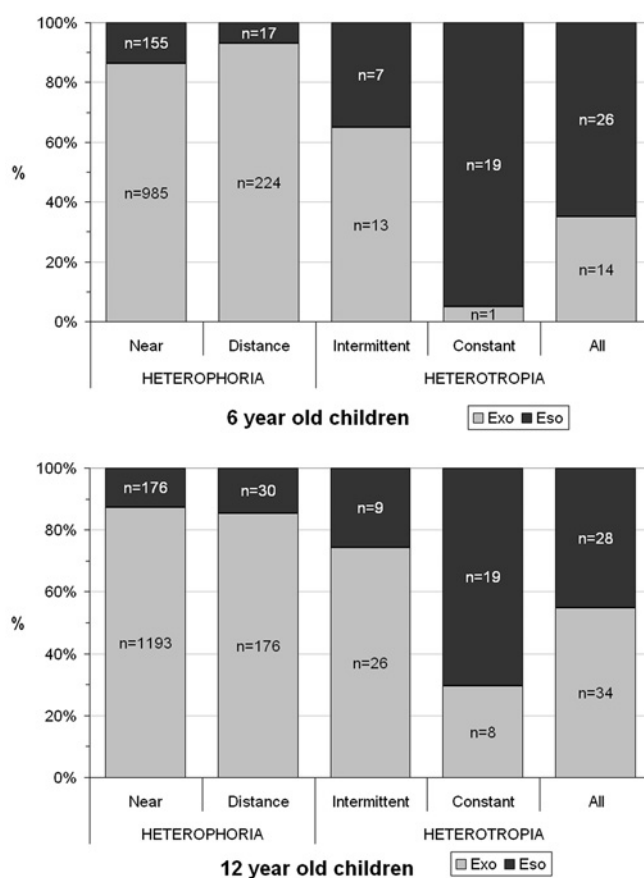


Figure 3 Proportions of horizontal heterophoria in comparison with proportions of intermittent, constant and all heterotropia in children aged 6 and 12 years.

result from the eyes being aligned for distance viewing of parallel light rays using tonic vergence.¹

While many studies of similarly aged children have reported that orthophoria is the most frequent state for near fixation,^{2 5 8} we found that exophoria predominated. After stratification, this finding persisted in the European Caucasian and East Asian populations. However, the children of East Asian ethnicity had significantly more exophoria and less esophoria than European Caucasian children, even after adjustment for refractive error. This parallels the high prevalence of predominantly intermittent exotropia in East Asian populations.²¹ Wider IPD has been attributed to East Asian populations,²² and it has been suggested that this may be linked to a higher prevalence of exophoria.²³ However, in our population, there was no statistical difference in IPD measures between European Caucasian and East Asian children. There must be another mechanism, not yet identified, contributing to more exophoria among East Asian children.

Heterophoria measured without wearing glasses was associated with refractive error. Esophoria was associated with hyperopia for both age groups, and this parallels the well-known association between esotropia and hyperopia, and may be due to the need for greater accommodative efforts to overcome hyperopia. Acting in concert with convergence, this tendency impacts on ocular alignment, causing an esodeviation.¹³ Exophoria was associated with myopia, but only in the 12-year age group. This association may be due to a reduced demand for accommodation. Again, it parallels the association between intermittent exotropia, particularly convergence weakness type²¹ and myopia. While a lack of accommodative effort may not in itself cause the ocular divergence, it may allow both eyes to assume a physiological position of rest, that is, slightly divergent. The orthophoric state may require slight amounts of accommodative convergence to maintain a parallel position of the eyes.¹

While they are very small in number, those with myopia and near esophoria are important clinically, because it has been reported that progressive additional lenses can significantly reduce myopic progression in this group.²⁴ This may help to reduce the development of pathological myopia, especially since this group is more prone to increased progression.²⁵

Clinical experience in the area of intermittent exotropia shows that it may be preceded by a large exophoria which has decompensated, and there is the expectation that intermittent esotropia may be preceded by an esophoria. In order to determine if decompensation of pre-existing heterophoria is the major developmental pathway for the appearance of some heterotropias, particularly intermittent heterotropias, longitudinal studies of heterophoria and incident heterotropia in children will be needed to establish this link.

Acknowledgements We thank the parents and children who participated in this study, and the principals and teachers who helped to facilitate it. We also thank the many health professionals who assisted in data collection, and the teams involved in data entry.

Funding Funding for the Sydney Myopia Study was provided by a grant from the Australian National Health & Medical Research Council (ID 253732) and the Vision Co-operative Research Centre. IGM's contribution was supported by a grant from the

Australian Research Council (COE561903). JFL holds a National Health and Medical Research Council Biomedical (Dora Lush) Postgraduate Research Scholarship (Scholarship ID 457173).

Competing interests None.

Ethics approval Ethics approval was provided by the University of Sydney Human Research Ethics Committee and Department of Education and Training NSW.

Patient consent Obtained.

Provenance and peer review Not commissioned; externally peer reviewed.

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