Monovision slows juvenile myopia progression unilaterally

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Aim: To evaluate the acceptability, effectiveness, and side effects of a monovision spectacle correction designed to reduce accommodation and myopia progression in schoolchildren.

Methods: Dominant eyes of 11 year old children with myopia (−1.00 to −3.00 D mean spherical equivalent) were corrected for distance; fellow eyes were uncorrected or corrected to keep the refractive imbalance ≤2.00 D. Myopia progression was followed by cycloplegic autorefraction and A-scan ultrasonography measures of vitreous chamber depth (VCD) for up to 30 months. Dynamic retinoscopy was used to assess accommodation while reading.

Results: All children accommodated to read with the distance corrected (dominant) eye. Thus, the near corrected eye experienced myopic defocus at all levels of accommodation. Myopia progression in the near corrected eyes was significantly slower than in the distance corrected eyes (inter-eye difference = 0.36 D/ year [95% CI: 0.54 to 0.19, p = 0.0015, n = 13]); difference in VCD elongation = 0.13 mm/year (95% CI: 0.18 to 0.08, p = 0.0003, n = 13). After refitting with conventional spectacles, the resultant anisometropia returned to baseline levels after 9–18 months.

Conclusions: Monovision is not effective in reducing accommodation in juvenile myopia. However, myopia progression was significantly reduced in the near corrected eye, suggesting that sustained myopic defocus slows axial elongation of the human eye.

METHODS

Participants were 18 children (11 female, seven male, mean age 11.6 years) with a variety of ethnic origins (10 east Asian, the remainder included white, south Asian (Indian), and Maori/Pasifica). Inclusion criteria were (i) 10–13 years of age, (ii) no previous spectacle or contact lens wear, (iii) both eyes having subjectively determined best sphere refractions 1.00 to 3.00 D with astigmatism ≤1.00 DC and initial anisometropia ≤1.00 D, (iv) both eyes correctable to 6/6 Snellen acuity, and (v) no binocular vision abnormalities or ocular pathology. Stereopsis was assessed using the Wirt circles of the Stereotest (Stereo Optical Inc, Chicago, IL, USA). Eye dominance was determined using a simple sighting test.

Abbreviations: ACD, anterior chamber depth; AXL, axial length; LT, lens thickness; PALs, progressive addition lenses; REML, restricted maximum likelihood; SER, spherical equivalent refraction; VCD, vitreous chamber depth
The study conformed to the tenets of the Declaration of Helsinki and was approved by the University of Auckland human subjects ethics committee. Informed consent in writing from parents and assent from children were obtained following written explanations and verbal discussion of the nature of the study and possible risks and benefits. Participants were free to withdraw at any time, but any suggestion that performance at school was compromised or any reduction in best corrected acuity in either eye, or the development of more than 1.00 D of anisometropia compared to baseline, resulted in automatic participant withdrawal. A maximum duration for monovision wear of 2½ years was specified, comparable with other studies. Data were periodically analysed and once a statistically significant result that fulfilled the aims had been obtained, the study was terminated. Terminations accounts for the variable duration of monovision wear (8–30 months) among participants. All participants were then prescribed conventional spectacles or monovision contact lens practice. The non-dominant eye was partially corrected to keep the imbalance between the eyes exceeded 2.00 D, when the non-dominant eye was corrected to maintain 6/6 acuity while keeping the refractive error equal to 2.00 D. As myopia progressed, the non-dominant eye was corrected to maintain 6/6 acuity while keeping the refractive error equal to 2.00 D. Participants were advised to build up to full time wear as quickly as possible. Spectacle wear was either full time (8 hours/day or more) or part-time.

Spherical equivalent refraction (SER), measured by cycloplegic autorefraction and vitreous chamber depth (VCD), measured by A-scan ultrasonography, were used to monitor myopia progression. Cycloplegia was induced with 1% tropicamide (two drops/eye, 5 minutes apart) after corneal anaesthesia with benoxinate: measures were made 30 minutes later. This protocol produces effective cycloplegia in children of this age. A portable autorefractor (Retinomax K-plus, Nikon Inc, Tokyo, Japan) was used to obtain two measures and was not masked to participant data. The accommodative status of the eyes when reading with the monovision prescription was determined by Cross-Nott dynamic streak retinoscopy. In this method, the working distance is varied in order to find the neutral retinoscopy reflex in each eye. At neutral, the plane of the retinoscope is varied in order to find the neutral retinoscopy distance because this is the most common procedure in monovision contact lens practice. The non-dominant eyes were used as the measure of SER. Ocular component dimensions (anterior chamber depth, ACD, lens thickness LT, and axial length, AXL) were measured by A-scan ultrasonography (Ophthasonic a-scan/b-scan III, Teknark Inc, St Louis, MO, USA). Vitreous chamber depth was computed as VCD = AXL - (ACD + LT) averaged form three measures for each eye. Measures were made on the day of the last retinoscopy check and at follow up visits approximately 8 months apart for an average period of 18.7 months (range 8–30 months). The same investigator (author) made all outcome measures and was not masked to participant data.

The accommodative status of the eyes when reading with the monovision prescription was determined by Cross-Nott dynamic streak retinoscopy. In this method, the working distance is varied in order to find the neutral retinoscopy reflex in each eye. At neutral, the plane of the retinoscope sight hold coincides with the point in space conjugate with the retina.

Linear mixed effects models were used to investigate the development of inter-eye differences over time. The model took account of the paired eyes, the repeated measures taken on the same eye and, importantly, the different number of measurements made per subject. The models were fit in SAS (SAS Institute Inc, USA) using the procedure PROC MIXED and the restricted maximum likelihood (REML) fitting algorithm.
eyes experienced myopic defocus at all levels of accommodation. Stereacuitity, which was 40 seconds of arc before recruitment, was typically reduced to between 40 seconds of arc and 80 seconds of arc with monovision, but returned to 40 seconds of arc with a conventional correction. Best corrected acuity remained at baseline levels (typically 6/5) in all eyes.

Refractive error versus time
The baseline SERs (table 1) of distance corrected eyes (−1.61 (0.62) D (mean (SD)) and near corrected eyes (−1.69 (0.67) D) were not different (p = 0.383). Myopia progression during monovision wear, computed as (SER(afterMV)−SER(baseline))×12/(months of wear), gave a mean progression rate across participants of −0.72 (0.32) D/year in distance corrected eyes and −0.32 (0.30) D/year in near corrected eyes. Figure 1A shows how the inter-eye difference in refraction (SER(dist)−SER(near)) developed over time for each of the participants and also the mixed model estimate of the average population trajectory with 95% confidence intervals. The model estimated the average

Figure 1 (A) Development of the difference in refractive error between distance and near corrected eyes (SER(dist)−SER(near)) for each of the 13 participants: the thick line shows the mixed effects model estimate of the average trajectory, with 95% confidence intervals (broken line). The negative slope (−0.36 D/year) indicates that myopia progressed more slowly in the near corrected eyes. (B) Development of the difference in vitreous chamber depth between the distance and the near corrected eyes (VCD(dist)−VCD(near)) for each of the 13 participants: the thick line shows the mixed effects model estimate of the average trajectory, with 95% confidence intervals (broken line). The positive slope (0.13 mm/year) indicates that the vitreous chamber elongated more slowly in the near corrected eyes.

RESULTS
Monovision spectacle wear
Table 1 shows participants’ eye dominance, sex, wear time, and measures of VCD and SER at baseline, after monovision wear, and following conventional spectacle wear. Not shown are details of children who dropped out of the study before the first follow up visit: two did not wish to continue with the cycloplegic measures, two moved abroad, and one could not be contacted. In table 1, two children (nos 6 and 7) were prescribed conventional spectacles after 18 months and 16 months because they were unhappy with their vision with monovision. Two children (nos 4 and 10) were prescribed conventional spectacles after 26 months and 13 months, respectively, because they developed more than 1.00 D of anisometropia relative to baseline. After several months of adaptation to monovision, dynamic retinoscopy (see Methods) showed that all children accommodated to read with the distance corrected (dominant) eye rather than with the near corrected eye. Consequently, the near corrected
difference in myopia progression between the eyes as 0.36 D/year (95% CI: 0.54 to 0.19, p = 0.0015, n = 13) with near corrected eyes progressing more slowly than distance corrected eyes. Similar analyses showed that no inter-eye differences developed for either J_R (p = 0.14) or J_L (p = 0.15). Analysis of the effect of part-time versus full-time wear of monovision suggested that the difference in progression rate (D/year) between the two eyes was less in part-time wearers (p = 0.04), but the difference in VCD elongation rate between the two eyes was not different for part-time and full-time wear (p = 0.11). Columns labelled “Final” in table 1 show non-cycloplegic subjective refractions for each eye after 9–18 months of conventional spectacle wear following the study period. Although significant levels of anisometropia (table 1) developed during monovision wear in some participants, final anisometropia (range 0.00 to 0.50 D) returned to equal baseline levels (p = 0.43) following conventional spectacle wear. Although these final measures were non-cycloplegic refractions, the data suggest that during conventional spectacle wear the loss of induced anisometropia was accounted for by a higher progression rate in the previously near corrected eyes (approximately 0.66 (0.51) D/year) than in the distance corrected eyes (approximately 0.46 (0.35) D/year) although these rates were not significantly different (p = 0.10).

Changes in ocular dimensions with time
The mean baseline VCDs of the distance and near corrected eyes were equal (17.02 (0.63) mm) with ranges of 15.98–18.42 mm and 16.04–18.35 mm respectively (table 1). Figure 1B shows the development of inter-eye difference in VCD between the distance and near corrected eyes (VCD(dist) – VCD(near)) over time for each of the participants. The mixed model analysis showed the mean difference in vitreous chamber elongation rate equalled 0.13 mm/year (95% CI: 0.18 to 0.08, p = 0.0003, n = 13), with the near corrected eyes elongating more slowly than the distance corrected eyes. Similar analyses showed that axial length increased more slowly in near corrected eyes than in distance corrected eyes (mean difference 0.10 mm/year (95% CI: 0.19 to 0.02, p = 0.016, n = 13) but no inter-eye differences developed for lens thickness (p = 0.253), anterior chamber depth (p = 0.509), or corneal radius (p = 0.451).

Correlation between changes in refractive error and vitreous chamber depth
Figure 2A shows the linear regression relations between the change in SER during monovision wear (SER(afterMV) – SER(baseline)) and the change in VCD (VCD(afterMV) – VCD(baseline)) for all eyes. With refractive error as the dependent variable, the slopes of the relations were similar (~2.16 D/mm, R = 0.81, for distance corrected eyes and ~2.22 D/mm, R = 0.88, for near corrected eyes). Thus, although the progression rates were different in the two eyes, both rates correlated closely with increases in VCD. Figure 2B illustrates the relation between the difference in refractive error (SER(dist) – SER(near)) and the difference in VCD between the distance and near corrected eyes (VCD(dist) – VCD(near)) at each visit for each participant. The slope of the relation obtained by linear regression (not shown) equalled −2.98 D/mm (R = 0.72).

DISCUSSION
The primary reason for investigating a monovision prescription was its potential to reduce accommodation. Unexpectedly, children accommodated to read with the distance corrected eye, so accommodation was not appreciably reduced by monovision. A possible explanation for this finding is that the accommodation response followed accommodation demand in the dominant eye, as reported for perceptually rivalrous stimuli.24 Another explanation (suggested by unpublished data from this laboratory) may be that accommodation was driven by the convergence necessary to maintain fusion while reading. Whatever the explanation, the result highlights the fact that undercorrecting one eye has quite different optical consequences than bilateral undercorrection. Bilateral undercorrection results in myopic defocus at distance but clear retinal images at near in both eyes. In contrast, unilateral undercorrection of the non-dominant eye results in continuous myopic defocus in the undercorrected eye at both distance and near. As expected,25 stereoacuity was reduced in some children with monovision but returned to 40 seconds of arc in all children with a balanced prescription. The best corrected acuity of all eyes remained at baseline levels (typically 6/5) throughout the study and based on these clinical tests there was no evidence of any change in visual function following monovision wear.

A significant finding was that the rate of myopia progression was slower in the near corrected eyes than in the distance corrected eyes. While participant dropout is of some concern, the demonstrated effect in 13 participants suggests that it can be generalised to at least 75% of the equivalent myopic population (p = 0.05).26 Although it is probable that the difference in progression rates can be attributed to a slowing of progression in the near corrected eyes because of sustained myopic defocus, the possibility of some increase in progression rate in the distance corrected eyes cannot be ruled out. Progression is typically most rapid during the initial stages of myopia development and slows to a stable refraction over a number of years.27 Accordingly, Grice et al28 reported a mean progression rate in the first year after myopia onset of ~0.87 D/year in a group of 19 children, whereas children with longer standing myopia (for example, those wearing single vision lenses as controls in PAL studies) typically have progression rates between 0.5–0.7 D/year.4,4,4,29 Therefore, while the progression rate in distance corrected eyes of ~0.72 D/year found in the present study is to be expected, that of ~0.32 D/year in near corrected eyes is lower than expected for children who had only recently developed myopia and were receiving their first optical correction.

For all eyes myopia progression was closely correlated with changes in VCD. The slopes of the relations were comparable to the theoretical value of ~2.70 D/mm30 suggesting that most of the difference in progression rate between the eyes could be accounted for by the difference in their vitreous chamber elongation rates. In conclusion, monovision is not effective in reducing accommodation in juvenile myopia. However, the results suggest that myopic retinal defocus acts as an anti-myo普惠ic stimulus that counters abnormal axial elongation of the human eye. This conclusion is the opposite of that reached after bilateral undercorrection of children with myopia2 but it is consistent with the results of animal studies.1,2,31

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Competing interests: The author has no financial interest in the outcome of this research.

Ethics statement: This study was approved by the University of Auckland Human Subjects Ethics Committee, which is accredited by the New Zealand Health Research Council.
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