Simulated Hyperopic Anisometropia and Reading, Visual Information Processing, and Reading-Related Eye Movement Performance in Children

Sumithira Narayanasamy,[1] Stephen J. Vincent,[1] Geoff P. Sampson,[2] and Joanne M. Wood[1]

[1]School of Optometry and Vision Science, Institute of Health and Biomedical Innovation, Queensland University of Technology, Brisbane, Australia
[2]School of Medicine (Optometry), Faculty of Health, Deakin University, Geelong, Australia

Correspondence: Sumithira Narayanasamy, School of Optometry and Vision Science, Institute of Health and Biomedical Innovation, Queensland University of Technology, Brisbane, Australia;
sumithira.narayanasamy@hdr.qut.edu.au.

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Purpose. This study investigated the impact of simulated hyperopic anisometropia and sustained near work on performance of academic-related measures in children.

Methods. Participants included 16 children (mean age: 11.1 ± 0.8 years) with minimal refractive error. Academic-related outcome measures included a reading test (Neale Analysis of Reading Ability), visual information–processing tests (Coding and Symbol Search subtests from the Wechsler Intelligence Scale for Children), and a reading-related eye movement test (Developmental Eye Movement test). Performance was assessed with and without 0.75 diopters of simulated monocular hyperopic defocus (administered in a randomized order), before and after 20 minutes of sustained near work. Unilateral hyperopic defocus was systematically assigned to either the dominant or nondominant sighting eye to evaluate the impact of ocular dominance on any performance decrements.

Results. Simulated hyperopic anisometropia and sustained near work both independently reduced performance on all of the outcome measures ($P < 0.001$). A significant interaction was also observed between simulated anisometropia and near work ($P < 0.05$), with the greatest decrement in performance observed during simulated anisometropia in combination with sustained near work. Laterality of the refractive error simulation (ocular dominance) did not significantly influence the outcome measures ($P > 0.05$). A reduction of up to 12% in performance was observed across the range of academic-related measures following sustained near work undertaken during the anisometropic simulation.

Conclusions. Simulated hyperopic anisometropia significantly impaired academic-related performance, particularly in combination with sustained near work. The impact of uncorrected habitual anisometropia on academic-related performance in children requires further investigation.

Keywords: eye movements, anisometropia, ocular dominance, visual information processing, reading performance

Anisometropia, an interocular difference in refractive error,[1] is an important pediatric refractive error, affecting up to 11% of children, depending on the definition of anisometropia and the age of the population studied.[1–6] Although a number of studies have examined the visual deficits associated with amblyopic anisometropia,[7,8] few studies have investigated the impact of uncorrected anisometropia on functional reading performance, visual information processing (VIP), and reading-related eye movements that are all relevant to children's performance in school. Thus, the minimum level of anisometropia that requires refractive correction in healthy children, separate from the risk of strabismus or amblyopia development, is unclear.[9–11]

Some older studies have reported an association between uncorrected anisometropia and impaired reading skills[12–15]; however, the mechanisms underlying this association have not been fully established (e.g., foveal suppression, altered binocular coordination, or aniso-accommodative stress).[9,16,17] A significantly higher prevalence of anisometropia has been observed in children classified as "reading disabled" or "poor readers" compared with age- and IQ-matched controls.[12,14] Additionally, Eames[13] reported that a significantly higher proportion of children with uncorrected hyperopic anisometropia were below their chronological reading age (using the Gates Silent Reading test) compared with a control group (65% and 24%, respectively). However, these studies failed to define the criteria used to classify children as "reading disabled," "poor readers," or "anisometropic," and may have included amblyopic anisometropes, which confounds the influence of anisometropia alone on functional measures relevant to school performance.

Other studies have sought to determine the minimum level of anisometropia that is of functional importance, by simulating anisometropia in adults and assessing binocularity (e.g., stereoacuity or suppression). Simulation of both spherical and astigmatic anisometropia as low as 1.00 diopter (D) has been shown to degrade binocular vision[9–11]; however, gross fusion remains intact at higher levels of anisometropia simulation

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under more natural conditions (up to 3.00 D when using Bagolini lenses).[9,10] Binocular rivalry leading to foveal suppression has been suggested as a possible mechanism underlying the reduction in performance in various outcome measures[9,18]; however, a recent study suggests that reading performance in adults does not differ significantly under monocular or binocular viewing conditions.[17] This supports the likelihood that a mechanism other than central suppression (e.g., altered vergence demand, aniso-accommodative stress, or altered sensory fusion) degrades reading performance in simulated anisometropia. Importantly, these adult simulation studies did not account for ocular dominance, which may be a potential confounding variable.[9–11] For example, inducing monocular defocus in front of the dominant eye (typically the right eye in 50%–80% of the population) could result in a greater reduction in performance (than if the simulation was induced in front of the nondominant eye) because it is the preferred eye for visual input.[19] The current evidence regarding the association between ocular dominance and functional reading performance is mixed, whereas some studies have reported superior performance in children with "fixed" dominance (an identifiable dominant eye),[20,21] others have found no such association.[22]

Although simulation studies offer valuable insight into the impact of uncorrected anisometropia on visual performance, previous studies have been limited to adults and have not included relevant functional tasks as outcome measures.[9–11] The impact of simulated anisometropia on standardized academic-related performance in children has not been investigated in detail. In addition, although children spend 4 to 5 hours each day on academic activities and have been shown to maintain constant near fixation for up to 16 minutes,[23] the impact of uncorrected anisometropia on sustained school-based near tasks has not been established. Therefore, the aim of the current study was to investigate the impact of simulated hyperopic anisometropia, combined with sustained near work, on a range of standardized academic-related measures in children. We also aimed to examine the influence of ocular dominance on changes in the outcome measures in the presence of simulated anisometropia. Our primary hypothesis was that simulated hyperopic anisometropia would significantly impair functional reading performance, VIP, and reading-related eye movements, which would be exacerbated following sustained near work. We also hypothesized that ocular dominance would influence the changes observed in these outcome measures and explored whether changes in stereoacuity underlie any reductions observed in the academic-related outcome measures as a result of simulated hyperopic anisometropia. A repeated measures design was used to control for potential differences between participants (such as socioeconomic status and IQ) and a range of standardized academic-related tasks that mirror common activities conducted in school classrooms were selected as outcome measures.

Methods

Sixteen visually healthy children (10 males and 6 females, mean age 11.1 ± 0.8 years), all of whom spoke English as their first language, were recruited from years 5 to 7 of local primary schools. Participants underwent a visual screening examination, including noncycloplegic retinoscopy, subjective refraction, monocular and binocular amplitude of accommodation, near point of convergence, random dot stereopsis (TNO test; Lameris Instrumenten BV, Utrecht, The Netherlands) and near horizontal dissociated heterophoria (Howell-Dwyer card; Cyclopean Design, Heathmont, Australia). Noncycloplegic retinoscopy has been shown to be accurate and suitable for refractive error screening in children in this age group.[24] During noncycloplegic retinoscopy, pupil size and the movement and brightness of the reflex were also monitored for accommodative fluctuations suggestive of accommodative control difficulties, latent hyperopia, or attentional or fixation changes. A fogging test with +1.50-D lenses over the optimal sphero-cylindrical refraction was also performed, and binocular distance visual acuity was remeasured. The repeated measures study design allows changes in outcome measures to be attributed to the hyperopic anisometropia simulation and/or the sustained near work. As such, the cycloplegic refractive status of the patient is not critical for explaining any observed changes to these variables. One participant (additional to the main cohort of 16) who failed the fogging test (an indication of latent hyperopia) was excluded from the study. Ocular sighting dominance was determined using a modified hole-in-the-card test during distance fixation.[25] Exclusion criteria included best-corrected visual acuity of worse than 0.00 logMAR in either eye, any significant refractive error (defined as spherical equivalent < -0.75 D or $> +0.75$ D, astigmatism >0.25 D, and spherical equivalent anisometropia >0.25 D), stereoacuity worse than 60 seconds of arc, strabismus, amblyopia, history of ocular disease or surgery, or any binocular vision anomaly. This study was conducted in accordance with the Declaration of Helsinki and was approved by the Queensland University of Technology Human Research Ethics Committee. All participants and their parents were given a full explanation of the experimental procedures, and written informed consent was obtained both from the participating children and their parent or guardian, with the option to withdraw from the study at any time.

This experiment was a within- and between-subjects design with within-subject factors including anisometropia simulation (with or without monocular hyperopic defocus of –0.75 D) and time (before and after 20 minutes of sustained near work). Laterality of the simulation with respect to ocular sighting dominance was included as a between-subject factor to evaluate its association with the observed changes in outcome measure performance.

Each participant completed two sessions that involved completion of a range of academic-related outcome measures for each of the two visual conditions (with and without the anisometropia simulation) before and after 20 minutes of sustained near work. A near task duration of 20 minutes was selected because children engage in school near tasks continuously for 16 minutes at a time.[23] During each session, the participants underwent assessment of all the outcome measures (20 minutes), followed by the sustained near work task (20 minutes) and reassessment of all the outcome measures (20 minutes). To minimize potential fatigue effects associated with the time taken to assess all the outcome measures, the order of the simulated visual conditions and the order in which the outcome measures were administered was randomized between participants.

Each participant wore their optimal refractive correction throughout all experimental procedures (full aperture lenses in a trial frame), with the minus lens placed in front of one eye during the hyperopic anisometropia simulation condition. A simulation level of 0.75 D was chosen for this study to investigate if a magnitude of anisometropia less than the current recommendations for refractive correction in children ($\geq$1.00 D hyperopic anisometropia)[26] has a detrimental effect on functional performance. Because both hyperopia[27–29] and anisometropia[13] have been linked with below average reading performance, we used a monocular hyperopic simulation instead of a bilateral asymmetric hyperopia simulation to isolate the impact of uncorrected anisometropia without the confounding influence of uncorrected ametropia (i.e., bilateral hyperopia).

Participants attended two separate visits, controlling for the time of day, with one visual condition simulated during each visit. Outcome measures were assessed immediately after the introduction of the hyperopic simulation lens, and again following sustained near work, during which participants were asked to perform pen-and-paper puzzles (N10 print). A constant working distance of 40 cm was maintained for all activities and regularly verified by the examiner. The monocular hyperopic defocus was induced in the dominant eye for half of the participants and the nondominant eye for the other half.

Outcome Measures

Reading Performance. The Neale Analysis of Reading Ability test is a widely used standardized measure of reading performance with published normative data available for Australian children.[30] The test assesses three main components of reading performance: rate, accuracy, and comprehension. The test consists of four individual forms, with each form consisting of six passages of increasing reading difficulty. One form was used during each assessment (two for each visit: before and after the sustained near task). Each passage was read aloud by the participant and was immediately followed by a series of comprehension questions. Testing was terminated if the maximum number of permissible reading errors was made. Reading rate (words per minute) was derived from the time taken to complete all of the individual passages using the following formula: (total words read/total time taken) $\times$ 60, in line with test instructions. For each passage, the total number of reading errors was subtracted from the maximum permissible errors for that particular passage and these values were summed for the six passages to provide the reading-accuracy score. Reading comprehension was quantified in terms of the total number of questions answered correctly.[31]

Visual Information–Processing Performance. The Wechsler Intelligence Scale for Children–Australian Standardized Edition (WISC-IV) is widely used for assessing the intellectual ability of children aged 6 to 16 years old, with published normative data available for Australian children.[32] The processing speed domain of this test consists of two subtests, Coding and Symbol Search, which were used to assess this aspect of VIP performance.

The Coding subtest provides a measure of speed and accuracy of visual motor coordination, attention skills, visual scanning, and tracking. Participants were presented with a rectangular grid of digits and instructed to substitute the appropriate symbol for each of the digits using a code that appears at the top of the page, and were required to complete as many items as possible within 120 seconds.

The Symbol Search subtest is a measure of perceptual discrimination, speed, accuracy, visual scanning, and visual motor coordination. Participants were presented with a horizontal array of symbols, divided into a target and a search group. They were instructed to scan the two groups and indicate whether the target symbols appear in the search group; as for the Coding subtest, they were required to complete as many items as possible within 120 seconds.

Eye Movement Performance. The Developmental Eye Movement (DEM) test was chosen to assess reading-related eye movement performance, as this test has been designed to control for rapid automatized naming (RAN) skills.[33] The DEM test consists of a pretest, two subtests with 40 numbers arranged in vertical columns (subtests A and B), and a subtest with 16 horizontal rows consisting of 80 irregularly spaced numbers (subtest C). The vertical subtest is designed to measure RAN ability, whereas the ratio of horizontal-to-vertical subtest times (after adjustment for errors) provides a measure of reading-related saccadic eye movements (RSEM), by controlling for RAN.[33] Developmental Eye Movement test scores are more highly correlated with academic test performance than with noncognitively-based quantitative eye movement measures.[34] Therefore, the DEM test is considered suitable for identifying children at risk of academic delays based on its association with reading ability and visual processing and its construct accounting for verbalization speed.[34] The test was administered according to the standard procedure.[33]

Stereoacuity was assessed immediately after the introduction of either the optimal refractive correction or the hyperopic anisometropia simulation to investigate any change in this measurement. The reading task and the assessment of all outcome measures were performed under photopic illumination conditions (620 lux).

Statistical Analysis

A three-way repeated measures ANOVA was used to examine the influence of refractive error simulation (with or without 0.75-D monocular hyperopic defocus) and time (before and after 20 minutes of sustained near work) on the various academic-related outcome measures. The laterality of imposed defocus with respect to ocular dominance was included as a between-subject factor to evaluate the influence of ocular dominance on the observed changes. All two-way and three-way interactions were examined. Nonparametric tests (the Wilcoxon Signed Rank and the Kruskal-Wallis tests) were conducted to investigate the impact of the monocular defocus on stereoacuity. Pearson's correlation was also used to investigate if changes in stereoacuity were potentially underlying the reductions observed in the academic-related outcome measures. The raw scores obtained from each academic-related outcome measure were used in the statistical analyses. A P value less than 0.05 was considered statistically significant. Raw scores were further converted to percentile ranks for each outcome measure to provide an estimate of the reduction in functional performance associated with sustained near work and the simulated anisometropia.

Results

All participants had minimal refractive error, with a group mean ($\pm$SD) spherical equivalent of +0.40 $\pm$ 0.36 D (range, −0.75 to +0.75 D) and 0.11 $\pm$ 0.13 D (range, 0–0.25 D) absolute spherical equivalent anisometropia. The mean reduction in binocular best-corrected visual acuity with the +1.50 D fogging lens (excluding the one participant with signs of latent hyperopia) was 0.65 $\pm$ 0.05 logMAR, as expected for this magnitude of imposed defocus if optimally corrected.[35] Binocular vision parameters were also within clinically normal limits for children in this age group[36–38]: monocular amplitude of accommodation (right eye mean: 13.75 $\pm$ 1.13 D, left eye mean: 13.69 $\pm$ 1.09 D, dominant eye mean: 13.94 $\pm$ 1.12 D, and nondominant eye mean: 13.50 $\pm$ 1.03 D), binocular amplitude of accommodation (mean: 14.44 $\pm$ 1.21 D), near point of convergence (mean: 5.25 $\pm$ 1.06 cm), stereoacuity (mean: 30.00 $\pm$ 13.42 seconds of arc), and near horizontal heterophoria (mean: 1.56 $\pm$ 2.92 Δ exophoria). Most participants had an above-average score for their age on all of the academic-related outcome measures (with a group mean equal to the 75th percentile). Table 1 displays the group mean

Table. Group Mean Reduction in Performance Relative to That With Optimal Refractive Correction Before Sustained Near Work, and the Results of the Relevant Statistical Comparisons for Each of the Outcome Measures

	Testing Conditions			$F_{1,14}$ Values for Repeated Measures ANOVA			
Outcome Measures	Optimal Refractive Correction After Near Work*	Simulated Anisometropia Before Near Work*	Simulated Anisometropia After Near Work*	Anisometropia	Near Work	Anisometropia × Near Work	Ocular Dominance
Reading performance†							
Rate, words per minute	−1.47 ± 1.07	−2.67 ± 0.95	−5.04 ± 1.82	143.77§	49.21§	5.16‖	2.46
Accuracy, words read correctly	−1.37 ± 0.81	−2.19 ± 1.22	−3.94 ± 1.57	59.63§	68.90§	1.52	0.52
Comprehension, questions answered correctly	−0.75 ± 0.68	−1.69 ± 1.62	−3.50 ± 1.10	75.56§	70.46§	9.24‖	1.37
VIP, WISC subtests†							
Coding, no. of correct responses	−1.25 ± 1.13	−2.19 ± 2.04	−4.56 ± 1.93	37.44§	70.93§	6.52‖	0.32
Symbol Search, no. of correct responses	−1.31 ± 1.08	−1.69 ± 1.14	−4.25 ± 1.13	84.43§	76.88§	10.69‖	2.17
DEM test‡							
Adjusted vertical time, s	1.03 ± 0.97	1.21 ± 0.99	2.81 ± 1.32	34.92§	33.86§	2.68	0.63
Adjusted horizontal time, s	1.07 ± 1.34	1.56 ± 1.05	3.97 ± 1.70	48.96§	37.86§	10.60‖	1.49
Ratio	0.002 ± 0.01	0.01 ± 0.01	0.02 ± 0.02	34.80§	14.06‖	8.90‖	2.00

* Mean ± SD reduction in performance relative to that achieved with optimal correction, before near work.
† Higher score indicates better performance.
‡ Higher score indicates poorer performance.
§ $P < 0.001$.
‖ $P < 0.05$.

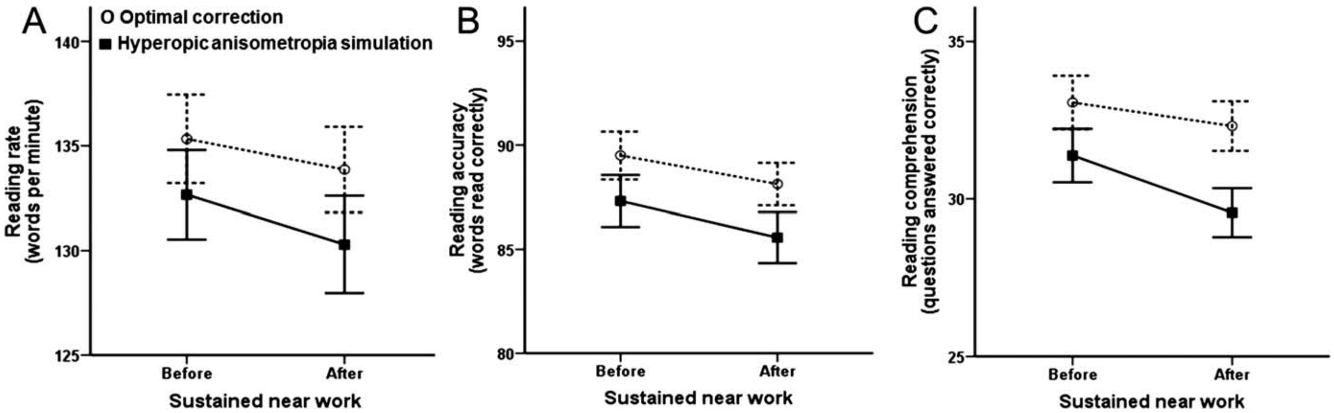

Figure 1. Mean reading performance (Neale Analysis of Reading Ability Test); rate (**A**), accuracy (**B**) and comprehension (**C**) before and after the 20-minute sustained near work task with and without the 0.75-D hyperopic anisometropia simulation (*error bars* represent the standard error of the mean).

reduction in performance relative to that with optimal refractive correction before sustained near work.

Reading Performance

Reading rate, accuracy, and comprehension were all significantly and independently reduced by simulated hyperopic anisometropia ($P < 0.001$) and sustained near work ($P < 0.001$), with a significant interaction between these factors for reading rate ($P = 0.04$) and comprehension ($P = 0.01$) (Fig. 1). There was no significant between-group effect of ocular dominance (whether the hyperopic defocus was imposed on the dominant or nondominant eye) and no other significant two-way or three-way interactions. Hyperopic anisometropia simulation alone resulted in a reduction in each of the reading components examined, including 2% for rate, 2% for accuracy, and 5% for comprehension. Performance reductions were twice as large during refractive error simulation in the presence of sustained near work: 4% (rate and accuracy) and 11% (comprehension).

Visual Information–Processing Performance

Performance on the Coding and Symbol Search subtests was significantly reduced by both simulated hyperopic anisometropia ($P < 0.001$) and sustained near work ($P < 0.001$). In addition, a significant interaction was also observed between hyperopic anisometropia simulation and sustained near work for both Coding ($P = 0.02$) and Symbol Search ($P = 0.01$) subtests (Fig. 2). There was no significant between-group effect of ocular dominance and no other significant two-way or three-way interactions, with the exception of a three-way interaction between simulated anisometropia, near work and ocular dominance for the Coding subtest only. This interaction occurred due to performance on the Coding subtest being more impaired following near work when anisometropia was simulated in the nondominant rather than the dominant eye. A reduction of 4% and 5% in performance was observed in Coding and Symbol Search, respectively, with combined sustained near work further exacerbating these reductions: Coding, 8%, and Symbol Search, 12%.

Reading-Related Eye Movement Performance

All three components of the DEM test (vertical time, horizontal time, and ratio) were significantly increased by both hyperopic anisometropia simulation ($P < 0.001$) and sustained near work: vertical time ($P < 0.001$), horizontal time ($P < 0.001$), and ratio ($P = 0.002$). A significant interaction also was observed for the DEM horizontal time ($P = 0.01$) and ratio ($P = 0.01$) between hyperopic anisometropia simulation and near work (Fig. 3) but there was no significant between-group effect of ocular dominance and no other significant two-way or three-way interactions. Slower vertical (3%) and horizontal (4%) times,

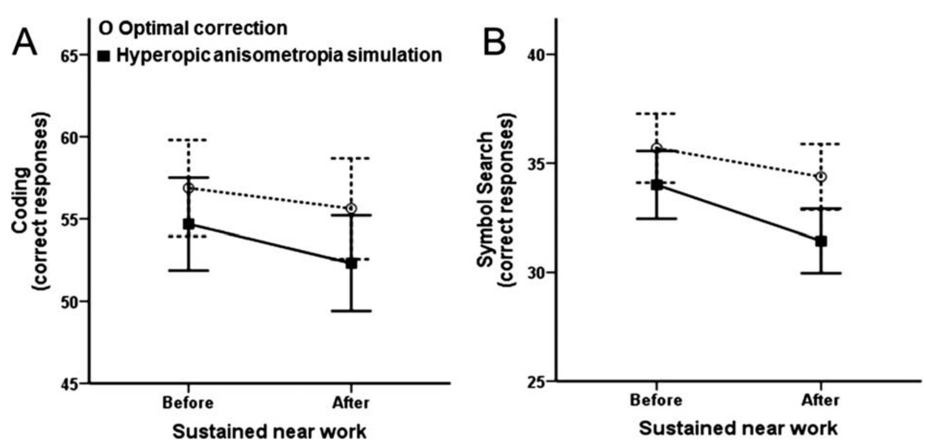

Figure 2. Mean VIP performance (WISC subtests); Coding (**A**) and Symbol Search (**B**) before and after the 20-minute sustained near work task with and without the 0.75-D hyperopic anisometropia simulation (*error bars* represent the standard error of the mean).

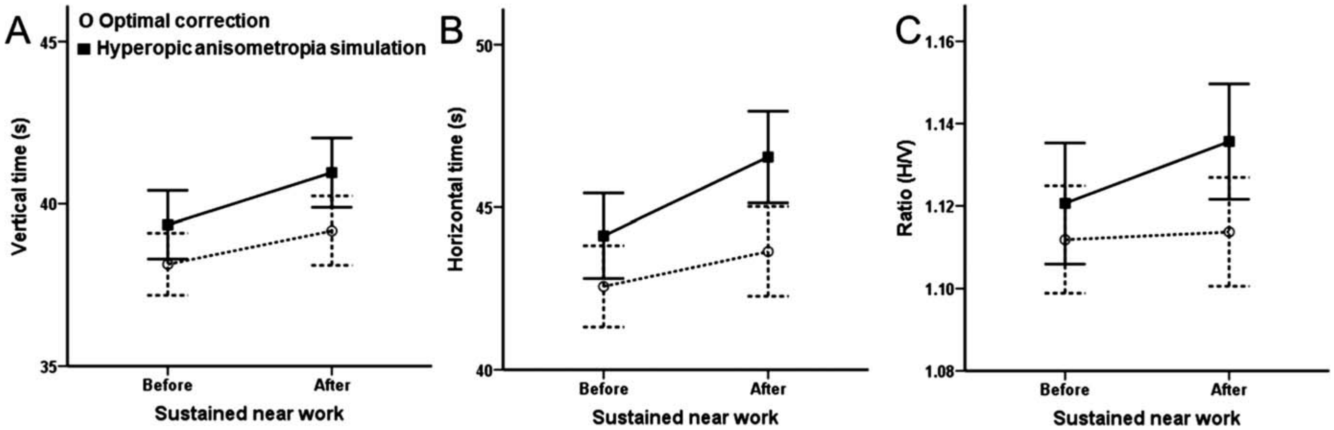

Figure 3. Mean DEM test performance; vertical time (**A**), horizontal time (**B**) and ratio (**C**) before and after the 20-minute sustained near work task with and without the 0.75-D hyperopic anisometropia simulation (*error bars* represent the standard error of the mean).

and an increased ratio (1%) were observed with simulated hyperopic anisometropia. These reductions in performance were greater in the presence of sustained near work: 7% in vertical time, 9% in horizontal time, and 3% in ratio.

A small but statistically significant reduction in stereoacuity was observed immediately following the introduction of the hyperopic anisometropia simulation ($Z = -2.41$, $P = 0.02$). This decrease in stereoacuity was similar regardless of whether the hyperopic defocus was added to the dominant (median: 0.00, interquartile range [IQR]: 0–30.00 seconds of arc) or nondominant eye (median: 7.50, IQR: 0–26.25 seconds of arc) ($\chi^2(1) = 0.09$, $P = 0.77$). There were no significant associations between this change in stereoacuity and the observed changes in any of the functional performance measures ($P > 0.05$).

Discussion

Consistent with our original hypothesis, a low level of simulated hyperopic anisometropia significantly impaired performance on a range of standardized academic-related measures in children with a normal visual profile. Sustained near work further exacerbated this effect (almost double the impact across all measures). However, we found that the decrement in performance was not dependent on the laterality of the simulation with respect to the sighting dominant eye.

All three aspects of reading performance assessed were impaired by simulated hyperopic anisometropia, with a larger decrement observed in the comprehension component, compared with rate and accuracy. A similar degradation in performance was also observed following sustained near work (without simulated anisometropia). Our results provide some support for the early work of Eames,[12,13] who reported an association between uncorrected hyperopic anisometropia and reduced reading performance, but failed to quantify reading status or account for potential confounding variables, such as coexisting ametropia or amblyopia. Our findings in children are also consistent with studies reporting poor reading performance in adults in the presence of simulated bilateral hyperopia,[39,40] which suggests that uncorrected hyperopia, either binocular or monocular, has a negative impact on reading performance.

Simulated hyperopic anisometropia also resulted in poorer performance on both VIP subtests: Coding and Symbol Search. These subtests involve activities performed within a specified time period and are quite similar to the near copying tasks commonly performed in classrooms, which suggests that students with low levels of uncorrected hyperopic anisometropia may potentially be disadvantaged when interpreting information presented at near or in a classroom environment, particularly following sustained near work. Further disadvantage may also be experienced while performing time-based tasks, such as examinations. This is an important finding given that visual stimuli form a major portion of learning materials used in classrooms.[41]

Hyperopic anisometropia simulation alone (i.e., without near work) led to a reduction in DEM test performance, with the greatest impact seen on the horizontal component compared with the vertical time and ratio. An even greater impact on each component was observed following sustained near work. Although the ability of the DEM test to represent saccadic eye movement capacity has been questioned, the DEM test correlates well with certain aspects of reading and visual-processing performance.[34] Our findings indicate that hyperopic anisometropia simulation results in impairment of both RAN and RSEM skills. The impact of simulated hyperopic anisometropia was greater for the horizontal component than vertical, resulting in an increased ratio, which suggests difficulties in reading tasks, given that this subtest has been shown to be associated with reading speed.[42] The previously reported association of DEM scores with reading and VIP scores[34] is consistent with the decrement in performance observed in both the Neale and VIP tests in the current study.

Another novel aspect of our study was the inclusion of a sustained (20-minute) near work component, which resulted in a small but significant decrement in performance on all of the academic-related measures even in the absence of the refractive error simulation. On average, the reduction in performance observed for all outcome measures following sustained near work alone was approximately two-thirds that observed during the hyperopic anisometropia simulation alone. Previous simulation studies in adults[9,10] have only investigated the influence of imposed refractive errors without a sustained near work component, which is a typical activity in most classrooms.[23] The findings of the current study strongly suggest that sustained near work alone has an impact on performance. This has implications, above and beyond the observed effect of simulated anisometropia, in terms of the length of time that children in this age group should be scheduled to perform tasks of this nature in the classroom, regardless of their refractive status. This finding has important implications for the management of classroom activities by teachers, given that academic activities in school are dominated by near tasks that require students to maintain continuous near fixation for extended periods.[23] Thus, frequent short breaks should be included between continuous near work activities to minimize visual fatigue, as this may affect students' ability to perform optimally in school.

Our findings suggest that a low level of hyperopic anisometropia, which may not typically be corrected according to established prescribing guidelines, results in a reduction of functional performance, especially in the presence of sustained near work, which was consistent with our primary hypothesis. However, at this stage, the significance of the observed changes in the outcome measures (Neale reading test, VIP subtests, and DEM) in terms of their impact on functional performance cannot be determined precisely, as there are limited references in the current literature to guide interpretation. Nevertheless, examination of the change in percentile ranks scores (an average of all the academic-related measures examined: Neale, VIP, and DEM tests) does provide some insight into the academic significance of these observed changes in outcome measures. On average, children's performance decreased from the 75th percentile to the 70th percentile during the simulation alone, and further to the 65th percentile following sustained near work, which suggests that children may perform below their full potential in the presence of uncorrected anisometropia. Therefore, children may benefit educationally from the refractive correction of relatively low levels of hyperopic anisometropia, and this further supports the recommendation by some authors that the correction of mild refractive errors ($\leq$0.75 D) may be beneficial, especially in symptomatic children.[43–45] Further investigations involving children with actual uncorrected hyperopic anisometropia are required to determine if such functional deficits do manifest in habitually anisometropic children, as these children may adapt to their uncorrected refractive error to some degree. Intervention studies (prescribing for low levels of anisometropia) would also enable determination of whether refractive correction would be of benefit to academic-related performance, similar to a recent study investigating the benefit of prescribing for low levels of uncorrected bilateral hyperopia on reading performance in children.[46]

However, our second hypothesis that imposing unilateral hyperopic defocus on the dominant eye may result in a greater decrement in performance compared with the nondominant eye was not supported. Indeed, performance on the VIP Coding subtest was in fact more impaired following near work when anisometropia was simulated in the nondominant eye; however, this was not observed for any other outcome measure. Our results for reading performance are in accord with a recent study that reported only a weak agreement between reading performance and ocular dominance in subjects with normal binocular vision.[17] The low magnitude of anisometropia simulated in our study (0.75 D) may also contribute to the negligible influence of ocular dominance. This is supported by Johansson et al.,[17] who suggested that ocular dominance may be a better predictor of reading performance in the presence of greater refractive error asymmetry between the eyes.

However, the actual mechanism underlying these changes in academic-related performance remains unclear. Although previous authors have proposed foveal suppression as a potential causative factor,[9–11] we observed a small but statistically significant reduction in stereoacuity during the refractive error simulation (mean 13.12 $\pm$ 18.06 seconds of arc), which indicates that high-level sensory fusion was only slightly disrupted. However, correlation analysis did not reveal any significant relationship between the magnitude of the reduction in stereoacuity and changes in any of the academic-related measures. This is most likely due to the preservation of gross fusion during the simulation.[9,10] Another possible explanation could be that the asymmetric hyperopic simulation resulted in an unequal accommodative demand between the fellow eyes. This could lead to stress on the accommodation-vergence system, which may be further exacerbated in the presence of sustained near work. This theory is based on evidence that aniso-accommodation may be possible to a certain extent in the presence of simulated anisometropia.[47–49] Future studies should investigate the possible association of aniso-accommodation on the functional impact caused by anisometropia simulation.

The results of this study should be considered in light of some potential limitations. We isolated the impact of uncorrected anisometropia by using a monocular hyperopic simulation rather than an asymmetric bilateral hyperopia simulation, which is a more common presentation in children with habitual hyperopic anisometropia. Therefore, these observed changes may underestimate the effect of actual (nonsimulated) uncorrected hyperopic anisometropia in children, whose performance may also be influenced by hyperopic ametropia in addition to the interocular refractive difference. Another consideration is that we included only children with minimal refractive error and normal binocular vision; thus, the introduction of monocular hyperopic defocus might result in a sudden change in the visual environment, altering the accommodation-vergence demand, whereas children with habitual anisometropia may exhibit partial adaptation to their refractive asymmetry. There was also minimal variation in performance of outcome measures between participants in our study, which may be attributed to the fact that the children included in our study were skewed toward above-average achievers. Although the current study found a statistically significant effect of anisometropia and near work on a range of outcome measures, extending the sample to a larger cohort of children, particularly those whose performance is below average for their age or school grade level, would provide greater insight into this relationship. The working distance adopted in this study (40 cm) also needs to be considered. Although this distance is commonly used in clinical settings,[50] studies have shown that some children may adopt a closer working distance when performing near tasks.[23,50] A constant working distance was used for all participants so as to avoid introducing a further confounding variable of each child's habitual near working distance. In addition, the time taken to complete all of the outcome measures may have resulted in a potential fatigue effect; however, this effect was minimized by randomizing the order in which the outcome measures were administered between participants.

The use of noncycloplegic refractive techniques to determine the refractive status of participants is another potential limitation, which may have underestimated the magnitude of any latent hyperopia to a small degree. However, we screened for possible latent hyperopes by using a fogging technique with bilateral +1.50-D lenses, a commonly used screening test,[51,52] and excluded one participant with latent hyperopia. The reduction observed in mean best-corrected visual acuity with the fogging lens (0.65 $\pm$ 0.05 logMAR) suggests that the participants included had minimal latent hyperopia.

This is the first study to examine the impact of simulated anisometropia on functional measures that are relevant to children. A low level of simulated hyperopic anisometropia resulted in poorer academic-related performance, with fatigue from sustained near work further exacerbating this effect. Therefore, early detection through vision screening and refractive correction for uncorrected anisometropia in children may potentially minimize functional disadvantage at school. However, future studies should ideally explore the impact of different magnitudes of both simulated and habitual uncorrected anisometropia on academic-related performance in children, as they may be affected differently in the presence of uncorrected hyperopic anisometropia.

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