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Title page

Impact of simulated hyperopia on academic-related performance in children

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ABSTRACT

Purpose: To investigate the impact of simulated hyperopia and sustained near work on children's ability to perform a range of academic-related tasks.

Methods: Fifteen visually normal children (mean age: 10.9 ± 0.8 years; 10 males and 5 females) were recruited. Performance on a range of standardised academic-related outcome measures was assessed with and without 2.50 D of simulated bilateral hyperopia (administered in a randomised order), before and after 20 minutes of sustained near work, at two separate testing sessions. Academic-related measures included a standardised reading test (the 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 (the Developmental Eye Movement test).

Results: Simulated bilateral hyperopia and sustained near work each independently impaired reading, visual information processing and reading-related eye movement performance ($p<0.001$). A significant interaction was also demonstrated between these factors ($p<0.001$), with the greatest decrement in performance observed when simulated hyperopia was combined with sustained near work. This combination resulted in performance reductions of between 5% and 24% across the range of academic-related measures. A significant moderate correlation was also found between the change in horizontal near heterophoria and the change in several of the academic-related outcome measures, following the addition of simulated hyperopia.

Conclusions: A relatively low level of simulated bilateral hyperopia impaired children's performance on a range of academic–related outcome measures, with sustained near work further exacerbating this effect. Further investigations are required to determine the impact of correcting low levels of hyperopia on academic performance in children.

Key Words: simulated hyperopia, children, academic performance

Hyperopia is a common refractive condition in children with a reported prevalence ranging from 0.4% to 26%, depending on the definition of hyperopia, age of children studied and measurement methods used (with or without cycloplegia).[1-8] In school aged children (5-17 years), while some clinicians consider +2.00 D as moderate hyperopia,[4, 7] others suggest that < +3.00 D is a relatively insignificant or low level of hyperopia.[8, 9] Importantly, the definition of clinically meaningful hyperopia varies (ranging from 1.25 to 2.00 D), making direct comparisons between studies difficult.[10] A number of studies have reported that uncorrected hyperopia is associated with poorer performance on measures of academic-related performance, such as reading ability.[11-22] The link between uncorrected hyperopia and academic performance may arise because the accommodative demand required to sustain clear focus during near tasks results in symptoms such as asthenopia, intermittent blurring of print, headaches and fatigue, which in turn may make it difficult to perform efficiently in the classroom.[23]

Although numerous studies have reported an association between uncorrected hyperopia and reduced academic performance in children, the majority of these studies have methodological limitations.[18, 22, 24] For example, many of these studies have employed either case control or cross sectional designs; [16, 17, 20] this allows identification of associations between uncorrected hyperopia and academic achievement, but cannot prove that the relationship is causal.[24] Another major limitation is inconsistency in defining and quantifying reading or academic performance.[18] A variety of descriptive terms have been used to categorise study participants, including ‘learning disabled’, ‘poor readers’, ‘slow readers’ and ‘reading disabled’, without providing precise definitions of what these terms mean.[25] This largely qualitative approach is further hampered by the use of non-standardised measures, such as a teacher’s subjective assessment,[11] or school derived exams,[17] to classify children into different academic performance groups. The validity and reliability of such measures are undetermined, and they employ an arbitrary selection of normal versus abnormal criteria; this limits the strength of the conclusions that can be drawn.[26] Poor statistical analysis techniques, such as failure to control for potential confounding factors or experimental bias are additional limiting factors.[24]

There is also a lack of consensus regarding the minimum level of uncorrected hyperopia that would detrimentally affect reading ability or general academic performance in children.[27] Survey findings from the Orinda study revealed that 50% of practitioners would consider bilateral hyperopia ≥ 1.50 D as the threshold for referral for further testing.[28] This was supported by Leat,[29] who recommended that hyperopia ≥ 1.50 D should be corrected during the school years. Similarly, Cotter[30] suggested that hyperopia ≥ 1.50 D should be corrected in symptomatic children, while Ciner[31] recommended that in children aged five and above, hyperopia ≥ 2.00 D should be corrected. However, each of these recommendations was based solely on the experience and clinical intuition of individual eye care practitioners, and not on evidence derived from well-designed studies.

There have also been attempts to empirically determine the magnitude of uncorrected hyperopia that is likely to be functionally problematic, but these investigations have been restricted to adults. Walton et al.[27] examined the impact of increasing levels of simulated hyperopia on performance of young adults' intelligence test scores, using the Otis Lennon Mental Ability Test. There was a significant decrease in test scores with 2.00 D of hyperopia simulation with a non-significant decrement in performance for 1.50 D. The authors concluded that uncorrected hyperopia of 1.50 D should be considered as the referral point for vision screening purposes while 2.00 D was regarded as the minimum threshold for ophthalmic correction of hyperopia. However, this study is limited by the fact that participants were not visually screened prior to inclusion in the study and thus other co-existing vision problems that may have influenced performance were not accounted for.

Garzia et al.[32] also showed that 2.00 D of simulated bilateral hyperopia caused a significant increase in reading time (but not accuracy) in visually normal adults; participants were screened prior to this study. A repeated measures design was used, where reading ability was assessed using a “cloze” procedure under two visual conditions; control (optimal refractive correction) and 2.00 D of hyperopia (simulated using minus lenses). While these studies suggest that uncorrected hyperopia between 1.50 to 2.00 D causes a significant decrement in reading performance in adults (especially reading speed), the impact of simulated hyperopia on standardised academic-related performance in children has not been assessed. In addition, these studies also did not attempt to identify the mechanisms underlying the observed changes in outcome measures with hyperopia simulation. Theoretically, uncorrected hyperopia leads to an increase in accommodative demand in order to maintain clear near vision, which may result in visual fatigue, especially when fixation needs to be sustained for long periods. Vergence demand may also be impacted, further complicating matters.[23] However, evidence to support this theory is scarce.

Near work activities such as reading and writing are considered the most important educational tasks undertaken by children.[33] Ritty et al.[33] reported that children spent around 4 to 5 hours daily on academic activities during school hours, with near tasks comprising about 54% of these activities. This study showed that on average, students maintained constant near fixation for an average of 16 minutes at a time.[33] However, previous reports linking uncorrected hyperopia with poor academic performance have not taken into consideration the possible effect of sustained near work.

The purpose of this study was to investigate the impact of a relatively low level of simulated bilateral hyperopic refractive error, combined with sustained near work, on a range of standardised academic-related measures in children. In addition, the change in vergence demand following the imposition of simulated hyperopia as a possible mechanism which may contribute to the observed changes in the outcome measures was also investigated. A repeated measures design approach was used to control for potential differences between participants (such as socioeconomic status and intelligent quotient) and specifically selected standardised academic-related outcome measures that mirror common activities usually conducted in school classrooms. These measures included the Neale Analysis of Reading Ability, the Coding and Symbol Search subtests (processing speed domain) of the Wechsler Intelligence Scale for Children-Australian Standardised Edition (WISC-IV) and the Developmental Eye Movement (DEM) test, which are all commonly used in vision or education research.[34-36]

METHODS

Participants and vision screening

Fifteen visually normal children (mean age 10.9 ± 0.8 years) were recruited from Years 5 to 7 of local primary schools through flyers outlining the study sent to academic and professional staff of Queensland University of Technology (QUT). The participants consisted of 10 males and 5 females, all of Caucasian ethnicity, who spoke English as their first language. Before testing, each participant underwent a visual screening examination to determine their refractive status, which included non-cycloplegic retinoscopy and subjective refraction (including binocular balancing using alternate occlusion). These methods have been shown to be accurate and suitable for refractive error screening in children.[37] During non-cycloplegic retinoscopy, pupil size and the movement and brightness of the reflex were monitored for accommodative fluctuations suggestive of accommodative control difficulties, latent hyperopia, attentional or fixation changes. In addition, children were fogged with +1.50 D lenses over their optimal sphero-cylindrical refraction and binocular distance visual acuity was remeasured. Two participants (additional to the main cohort of 15) demonstrating signs of significant latent hyperopia (failed the fogging test) were thus excluded from the study. A range of binocular vision parameters were also evaluated, including monocular and binocular amplitudes of accommodation (push-up method), near point of convergence, stereopsis (TNO test) and near horizontal dissociated heterophoria (Howell-Dwyer card, Cyclopean Design, Heathmont, Australia). Participants were excluded if they had visual acuity worse than 0.00 logMAR in either eye, stereoacuity greater than 60 seconds of arc, any strabismus or amblyopia, any history of ocular disease or surgery, or any known binocular vision abnormality. One participant who did not meet the visual acuity inclusion requirement was excluded during the vision screening. This study was conducted in accordance with the Declaration of Helsinki and was approved by the QUT Human Research Ethics Committee. Written informed consent was also obtained from the participants and their parents following a full explanation of the experimental procedures. Participants had the option to withdraw from the study at any time.

Experimental design

The academic-related outcome measures were measured binocularly for each participant under two visual conditions (administered in a randomized order), and at two separate time points using a repeated measures design:

- Control condition (optimal sphero-cyclinder correction with plano lens addition binocularly)
- Hyperopia simulation condition (optimal sphero-cyclinder correction with minus 2.50 D lens addition binocularly)

Each participant wore their optimal refractive correction throughout all experimental procedures, with the minus lenses added to this during the hyperopia simulation condition. Pilot studies conducted on both visually normal adults and children suggested that a detrimental impact on a range of standardised academic-related measures resulted from between 2.00 to 3.00 D of bilateral hyperopia simulation. Therefore, 2.50 D, the intermediate level of this range, was selected for this study to achieve balance between investigating a realistic level of uncorrected hyperopia that may be found in children, and demonstrating an effect of this low level on academic-related performance. In addition, studies on adults have also shown that simulated hyperopia between 1.50 D to 2.00 D impacts on functional performance.[27, 32] Given that children have greater accommodative reserve compared to adults, we decided that a higher level of hyperopia simulation would be required to observe a reduction in performance.

Testing was conducted on two separate visits, controlling for the time of the day, with participants being assessed under only one visual condition during each visit. Measurements were conducted immediately following the introduction of control or hyperopia simulation lenses (using full aperture trial lenses placed in a trial frame), and repeated again after 20 minutes of sustained near work (with the simulation lenses still in place). During this 20 minutes, participants performed pen and paper puzzles comprised of N10 print at a working distance of 40cm (which is a common near testing distance in clinical settings).[38] This task duration was selected based on a previous study which reported that on average, school children engage in near point tasks continuously for about 16 minutes at a time.[33] A reading board was used throughout each near task to ensure a constant working distance between participants and across experimental sessions. The examiner also verified that the correct working distance was being maintained by participants at regular intervals throughout the testing session. The order in which the outcome measures were administered was randomised between participants to minimise potential order effects.

Reading performance

The Neale Analysis of Reading Ability test was selected to assess reading performance. This is a widely used standardised measure of reading performance with published normative data available for Australian children.[39] 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 upon completion of the passage. Testing is terminated if the maximum number of permissible reading errors is made. However, all participants successfully completed all six passages included in every form, so termination of the test was not required for any of the participants. 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) x 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.[40]

Visual Information Processing (VIP) performance

Processing speed is considered to be linked to many cognitive skills such as word recognition and reading comprehension.[41] Therefore, any abnormalities in processing speed may lead to difficulties with the learning process and comprehension of new information in children.[41] The Wechsler Intelligence Scale for Children - Australian Standardised 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.[42] The processing speed domain of this test consists of two subtests, Coding and Symbol Search, which were used to assess VIP performance. The processing speed domain assesses a child's ability to focus attention and quickly scan, discriminate between, and sequentially order visual information.

Coding: This subtest is 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. They were required to complete as many items as possible within 120 seconds, and the number of correct responses was recorded.

Symbol Search: This 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 with the Coding subtest, they were required to complete as many items as possible within 120 seconds. The number of correct responses was recorded.

Developmental Eye Movement (DEM) test

The DEM test was chosen to assess reading-related eye movement performance as it is simple and quick to administer with children[43] and is commonly used clinically to assess automaticity in number naming and ocular motor fluency in reading.[12, 44] The DEM test consists of a pre-test, 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 rapid automatised naming (RAN) ability while 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.[44] However, questions have been raised regarding whether the DEM test strictly measures saccadic eye movement ability; DEM scores have been shown to correlate better with academic test performance than with other quantitative eye movement measures.[34] Nevertheless, 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 verbalisation speed.[34] In line with standard administration procedures, participants were asked to read the single digit numbers aloud as quickly and accurately as possible. The times taken to complete the two vertical columns (RAN) and sixteen horizontal lines were separately recorded. The horizontal test times were adjusted for errors in reporting the numbers, and, upon completion, a ratio (RSEM) of horizontal to vertical time was calculated.

Near horizontal dissociated heterophoria

Near horizontal dissociated heterophoria was measured using the near Howell-Dwyer Phoria card (Cyclopean Design, Heathmont, Australia) at a distance of 33cm. A loose dissociating prism of 6Δ base-down was introduced in front of the right eye and the participant was asked to identify the number most closely aligned with the top arrow.[45] This was conducted immediately following the introduction of either the optimal refractive correction or the hyperopia simulation lenses to investigate any change in near heterophoria.

All outcome measures were assessed under photopic illumination conditions (620 lux).

Statistical analysis

Statistical analysis was performed using SPSS 19.0. A two way repeated measures analysis of variance (ANOVA) was used to examine the influence of refractive error simulation (with and without -2.50 lens addition) and time (before and after 20 minutes of sustained near work) on the various academic-related outcome measures. A p-value of less than 0.05 was considered statistically significant. Pearson's correlation analysis was conducted to examine the relationship between changes in the academic-related performance measures and the change in near horizontal heterophoria following addition of the hyperopia simulation lenses. This was undertaken to investigate if vergence alignment might be one potential factor associated with the observed changes, given that hyperopia simulation will also induce change in vergence posture at near in most children.

RESULTS

All participants had minimal refractive error (group mean spherical equivalent of +0.30 ± 0.29 D, range: -0.25 to + 0.75 D). No subject exhibited anisometropia greater than 0.50 D or astigmatism greater than 0.50 D and all had best corrected visual acuity of 0.00 logMAR or better in either eye. The mean reduction in binocular best corrected visual acuity with the +1.50 D fogging lens (excluding the two participants with signs of latent hyperopia) was 0.66 ± 0.07 logMAR (as expected for this magnitude of imposed defocus if optimally corrected).[46] Binocular amplitudes of accommodation (mean: 14.33 ± 1.34 D), near point of convergence (mean: 4.87 ± 1.68 cm), stereoacuity (mean: 27.00 ± 6.21 seconds of arc) and near horizontal heterophoria (mean: 1.87 ± 2.56 Δ exophoria) were within clinically acceptable normal limits for children in this age group,[47-49] although it is acknowledged that the criteria for normal cut-off values vary between authors.[50, 51] Baseline data also indicated that most of the participants had an above average score on all the academic-related outcome measures (approximately in the 70th percentile for their age group), which was not unexpected given that the participants recruited were children of academic and professional staff of the University.

Table 1 shows the group mean reduction relative to optimal correction before sustained near work and results of the statistical comparisons for each of the outcome measures with the optimal refractive correction and the 2.50 D bilateral hyperopia simulation, before and after 20 minutes of sustained near work.

Table 1 here

Reading performance

All three components of reading performance assessed (rate, accuracy and comprehension) were significantly reduced by both simulated hyperopia ($p<0.001$) and sustained near work ($p<0.001$).

There was also a significant interaction ($p<0.001$) between simulated hyperopia and near work for each of these components (Figure 1).

Figure 1 here

Visual information processing performance

The number of correct responses in the Coding and Symbol Search subtests was significantly reduced by both simulated bilateral hyperopia ($p<0.001$) and sustained near work ($p<0.001$). In addition there was also a significant interaction effect ($p<0.001$) between hyperopia simulation and sustained near work for both of these VIP tests (Figure 2).

Figure 2 here

Reading-related eye movement performance

Vertical and horizontal DEM subtest times, as well as the ratio were significantly increased by both bilateral hyperopia simulation ($p<0.001$) and sustained near work ($p<0.001$). A significant interaction effect ($p<0.001$) between hyperopia simulation and near work was also observed for each of these DEM parameters (Figure 3).

Figure 3 here

Mean dissociated horizontal near heterophoria with optimal correction was 1.87 ± 2.56 Δ exophoria and 2.80 ± 4.86 Δ esophoria with the 2.50 D hyperopia simulation in place. The correlation between the change in near horizontal heterophoria and the change in academic-related outcomes following addition of the hyperopia simulation lenses are summarised in Table 2. Significant positive correlations were observed for reading accuracy, Coding and Symbol Search WISC subtests.

Table 2 here

DISCUSSION

The impact of simulated hyperopia on standardised academic-related measures in children before and after a period of sustained near work was examined in this study. There was a statistically significant main effect of both simulated hyperopia and sustained near work on these measures, as well as a significant interaction between simulated hyperopia and sustained near work for the majority of the outcome measures. To the best of our knowledge, this is the first study to investigate the impact of hyperopia simulation on academic-related measures in children. An important aspect of this study was the inclusion of a sustained near work component, of a duration that has been shown to reflect what children are expected to regularly undergo whilst at school.[33]

Results of this study demonstrated that hyperopia simulation alone resulted in impaired reading performance, with the largest decrement being observed in the comprehension measure (5%) followed by reading rate (2%) and accuracy (2%), and each of these effects were exacerbated following sustained near work (comprehension (21%), rate (9%) and accuracy (9%)). These results are in general accord with findings in adults from Garzia et al.,[32] who investigated the impact of induced hyperopia of 2.00 D on reading performance and found that reading rate was significantly impaired (by up to 11%). However, there was no significant change in the reading accuracy of their adult participants with hyperopia simulation (1.5% reduction). They suggested that an increased time for reading was required in order to maintain reading accuracy in the presence of the induced hyperopia. Given that children are less experienced readers than adults,[52] it is likely that any impairment of the visual system may have a greater impact on overall reading performance (including reading rate, accuracy and comprehension) in children, as shown in the current study, relative to that of adults. These differences could also be due to the different reading assessment tools used in each study. This is an important finding given that the reading components evaluated by the Neale test (rate, accuracy and comprehension) are fundamental to the everyday learning process in schools.[53] Children with uncorrected hyperopia may face difficulty in optimally developing this essential learning skill, which subsequently may produce a barrier for their overall academic achievement during the 'reading to learn' phase.[54]

As far as we are aware, this is the first study to explore the impact of simulated hyperopia on VIP, which are important skills required by children to enable them to extract and organise visual input from the environment.[55, 56] Hyperopia simulation alone resulted in poorer performance on both the Coding and Symbol Search WISC subtests, which require the participants to quickly scan, discriminate and sequentially order visual information (with a 5% and 6% reduction respectively). A greater decrease in performance was observed following sustained near work in the presence of the hyperopia simulation with a 24% reduction in performance for each of these subtests. This decrement in performance suggests that those with uncorrected hyperopia may be less efficient at interpreting visually presented information, which may be a disadvantage when undertaking academic activities that need to be completed within a limited time frame, such as school based exams.

Simulated bilateral hyperopia also resulted in slower vertical and horizontal DEM times (both 6% slower) and an increase in the ratio component (0.9%). These reductions in performance were further exacerbated after sustained near work (vertical time (16%), horizontal time (19%) and ratio (4%)). Garzia et al.[44] proposed that the vertical subtest of DEM measures RAN skills, while the horizontal subtest measures ocular fixation and saccadic skills, while controlling for visual to verbal transfer automaticity. Therefore, the increased vertical and horizontal times observed in the current study suggest that both RAN and RSEM difficulties may result from hyperopia simulation. The impact of simulated hyperopia was greater for the horizontal component than vertical, resulting in an increased ratio. Overall, this finding suggests that simulated hyperopia may compromise reading-related eye movements and visual processing performance, skills that are considered to be important for children to achieve academically.[18, 57] Ayton et al.[34] reported that the DEM test is correlated with aspects of reading and visual processing performance, even though it is not significantly correlated with quantitative measures of eye movements. The relationship between the DEM test and reading performance was also examined by Palomo-Alvarez & Puell,[58] who reported a negative correlation between reading speed and the time to complete the DEM horizontal subtest.

However, while the observed changes in reading, VIP and reading-related eye movement performance due to simulated hyperopia were statistically significant in this sample of children, it is difficult to comment on the educational significance of these changes. The reason for this is that there are no established guidelines as to what constitutes a clinically or academically significant reduction for the outcome measures used in this study. However, 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 hyperopia simulation and sustained near work. On average, children's performance dropped from the 70th percentile to the 63rd percentile during the hyperopia simulation alone and further to the 46th percentile following sustained near work, with 52% of the participants falling 'below average' (lower than the 50th percentile). Whilst these levels do not constitute a low level of functioning, these findings do suggest that a significant proportion of children may perform substantially below their capability in the presence of simulated hyperopia.

An important finding in the current study was that sustained near work (for a period of 20 minutes) resulted in a small but statistically significant decrement in each of the academic-related measures included in this study, even in the absence of simulated hyperopia. A previous study investigating ergonomic demands in primary school classrooms highlighted the finding that about 50% of the student's activities were focussed on near tasks such as reading and writing.[33] On average, students were required to maintain near fixation for approximately 16 minutes at any one time.[33] Therefore, results of this current study have implications for daily classroom activity planning by teachers. Regular break times are necessary to avoid visual fatigue, which may be detrimental to a student's academic performance in school especially in the presence of uncorrected hyperopia.

This study demonstrated that bilateral hyperopia simulation of 2.50 D resulted in a significant decrease in performance for a range of outcome measures, which were exacerbated when accompanied by sustained near work. This indicates that uncorrected bilateral hyperopia may be detrimental to academic-related performance in children, especially in the presence of continuous near fixation. While 2.50 D of hyperopia is considered a relatively low level of refractive error in young children,[8, 9] many children may manifest an even lower degree of uncorrected hyperopia. Such children may also be affected academically, as observed in this study, but to a lesser extent. However, the dioptric cut-off level that would provide a negative impact on academic performance cannot be readily ascertained using the study design adopted here. Importantly, our results are in accord with previous prescribing guidelines for hyperopia that were primarily designed to prevent amblyopia and largely rely on clinical intuition; this suggests that refractive correction for this level of uncorrected hyperopia would potentially benefit children in relation to academic related activities.[16, 20, 29] However, factors such as a child's current academic performance at school, amount of near work and binocular vision status should all be taken into consideration.[30] These results additionally indicate that it is important to screen for uncorrected hyperopia in children in order to minimise potential functional disadvantage at school. Vision screening protocols should include clinical techniques such as fogging lenses to detect low levels of hyperopia.

The exact mechanisms that drive the observed decrease in performance across the different academic-related measures are unclear. One possible explanation for these changes was explored in this study; namely that increased vergence demand associated with the hyperopic simulation may contribute to the observed functional decrements. The findings obtained provide some support for this hypothesis by demonstrating a significant although moderate correlation between the change in near horizontal heterophoria and the change in several of the outcome measures (reading accuracy and VIP subtests); this suggests that a greater esophoric shift was associated with a greater reduction in performance. This implies that the increase in accommodative demand associated with hyperopia simulation may not be the only factor involved with the reduction in performance of the academic-related measures and changes to vergence demand may also be contributing. The relative impacts of accommodation and vergence demand are difficult to tease out precisely and would be likely to vary from child to child, depending on their uncorrected vergence posture and fusional vergence reserves. It may not be essential to separately measure the impact of each of these individually given that they effectively occur as a single entity; uncorrected hyperopes would experience a relative esophoric shift while they remain uncorrected. Nonetheless, findings of this study highlight the need for further investigation to explore these associations more systematically.

An advantage of this study was the use of a repeated measures design which allows for the control of other potential variables such as intelligent quotient and socioeconomic status which may differ between participants. This was not accounted for in previous studies investigating the relationship between uncorrected hyperopia and academic performance.[16, 17, 20] However, there are some potential limitations in this design which need to be considered when interpreting the findings. While simulation of refractive error is a common research methodology,[59-62] the pseudo-refractive error scenario used in this experiment does not necessarily equate to actual uncorrected refractive errors in children. In this study the effects observed may be artificially inflated compared to children with habitual uncorrected hyperopia who may have partially adapted to their condition. Despite this limitation, the repeated measures simulation approach allowed us to isolate the impact of hyperopia alone without introducing inter-individual variations in performance. Another potential limitation of this study was that the participants were generally skewed towards above average achievers, which may explain the minimal variation between participants in the results. An additional issue that needs to be taken into consideration is the working distance that was adopted in this study (40 cm). Even though this is commonly used in clinical settings,[38] some studies have shown that children may adopt a shorter working distance when performing near tasks (approximately 30 cm).[33, 38] This shorter distance would impose higher accommodative demand and is likely to further worsen the functional impact of uncorrected hyperopia on measures of academic performance.

The use of non-cycloplegic measures to determine the refractive errors of the participants in this study may have underestimated any latent hyperopia and therefore influenced the overall amount of hyperopia that was simulated. However, a fogging technique (+1.50 D bilateral blur) was used to screen for potential latent hyperopes (which resulted in two potential participants were excluded from the study). The mean reduction in binocular best corrected visual acuity with the +1.50 D fogging lens was 0.66 ± 0.07 logMAR (over six lines reduction in acuity). This reduction in visual acuity suggests that the emmetropic participants in this current study had minimal latent hyperopia. This is consistent with Fotedar et al.[7] who reported that emmetropic 12 years olds showed minimal manifestation of hyperopia following cycloplegia (0.25 D to 0.50 D more hyperopia).

In summary, this study demonstrated that a low level of simulated hyperopia in children resulted in impaired performance on a range of academic-related measures, with fatigue from sustained near work appearing to further exacerbate this effect. Future studies should explore the impact of different magnitudes of both bilateral and unilateral simulated hyperopia and importantly explore these relationships in those with habitual uncorrected hyperopia in children. Such studies should also include children with a wider range of academic ability, particularly those whose performance is below average for their age or school grade level as they may be disadvantaged to a greater extent in the presence of uncorrected hyperopia. It would also be useful to further explore the factors underlying the changes in performance measures observed in this study.

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FIGURE LEGENDS

Figure 1: Mean reading performance; rate (A), accuracy (B) and comprehension (C) before and after the 20 minute sustained near work task with and without 2.50 D bilateral hyperopia simulation (error bars represent the standard error of the mean).

Figure 2: Mean VIP performance; Coding (A) and Symbol Search (B) before and after the 20 minute sustained near work task with and without 2.50 D bilateral hyperopia simulation (error bars represent the standard error of the mean).

Figure 3: Mean DEM performance; vertical time (A), horizontal time (B) and ratio (C) before and after the 20 minute sustained near work task with and without 2.50 D bilateral hyperopia simulation (error bars represent the standard error of the mean).

Table 1:

Measures	Mean Reduction in Performance (SD)			$F_{(1,14)}$ for repeated measures ANOVA		
	Optimal refractive correction	2.5D hyperopia simulation				
	After 20 minutes near work	Before 20 minutes near work	After 20 minutes near work	Hyperopia simulation	Sustained near work	Hyperopia simulation x sustained near work
Reading performance [a]						
Rate (words per minute)	-1.62 (1.10)	-9.99 (4.33)	-12.73 (4.98)	86.76*	106.53*	50.33*
Accuracy (number of words read correctly)	-1.53 (0.83)	-5.73 (2.15)	-7.73 (2.58)	103.52*	124.69*	61.33*
Comprehension (number of questions answered correctly)	-1.13 (0.74)	-5.47 (2.23)	-7.20 (2.24)	147.87*	112.10*	53.77*
Visual Information Processing (VIP) (WISC subtests)[a]						
Coding (number of correct responses)	-1.60 (1.06)	-9.33 (4.58)	-11.87 (5.05)	73.77*	85.11*	38.89*
Symbol Search (number of correct responses)	-1.40 (0.99	-5.73 (3.73)	-7.73 (3.56)	90.39*	47.61*	20.40*
Developmental Eye Movement test (DEM)[b]						
Adjusted vertical time (s)	1.48 (1.05)	4.11 (3.47)	6.41 (4.14)	34.48*	33.54*	8.39*
Adjusted horizontal time (s)	1.67 (1.53)	5.62 (3.25)	8.60 (4.51)	53.80*	52.97*	21.87*
Ratio	0.00 (0.01)	0.03 (0.04)	0.04 (0.05)	10.91*	7.81*	7.88*

* $p<0.001$

[a] Higher score indicates better performance

[b] Higher score indicates poorer performance

Table 2:

Outcome measures	R value
Reading performance	
Rate	0.28
Accuracy	0.55*
Comprehension	-0.03
VIP performance	
Coding	0.54*
Symbol Search	0.64*
DEM performance	
Adjusted vertical time	0.39
Adjusted horizontal time	-0.24
Ratio	0.20

*$p<0.05$

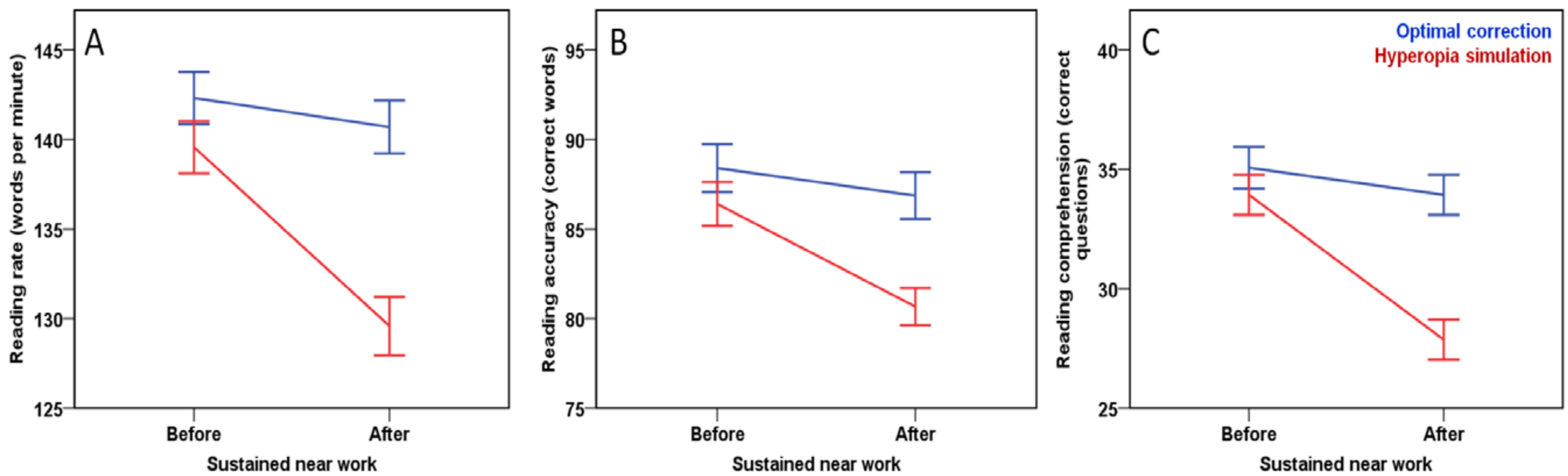

Figure 1: Mean reading performance; rate (A), accuracy (B) and comprehension (C) before and after the 20 minute sustained near work task with and without 2.50 D bilateral hyperopia simulation (error bars represent the standard error of the mean).

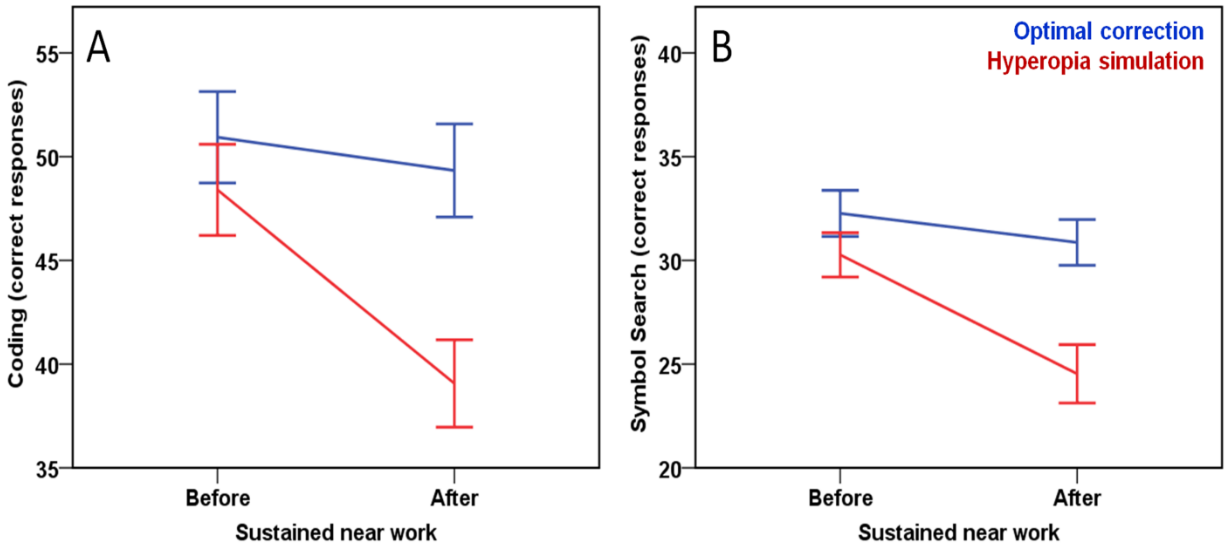

Figure 2: Mean VIP performance; Coding (A) and Symbol Search (B) before and after the 20 minute sustained near work task with and without 2.50 D bilateral hyperopia simulation (error bars represent the standard error of the mean).

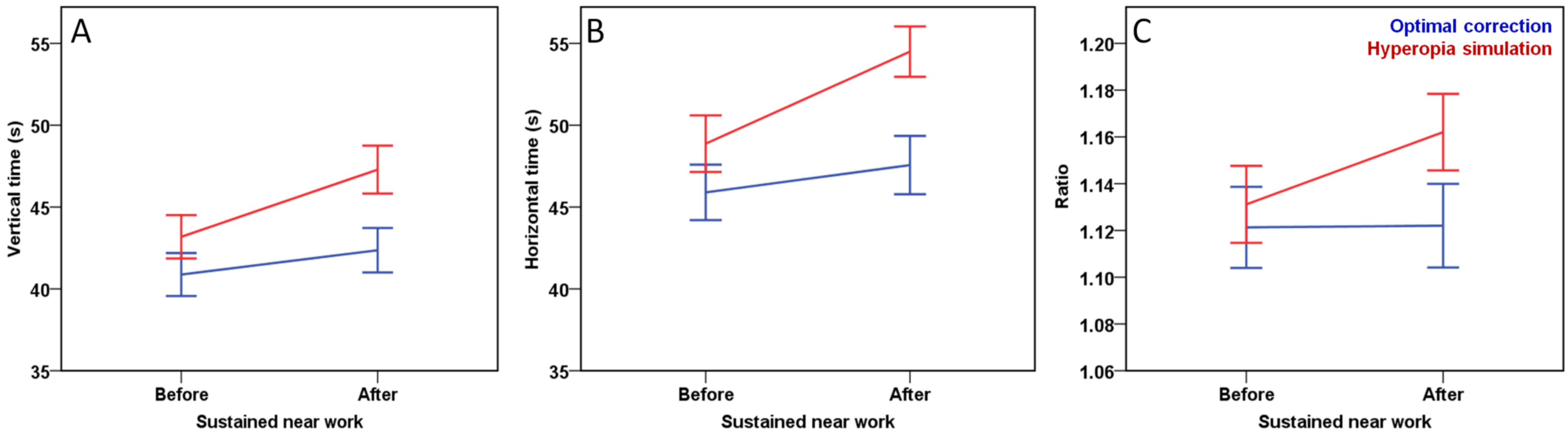

Figure 3: Mean DEM performance; vertical time (A), horizontal time (B) and ratio (C) before and after the 20 minute sustained near work task with and without 2.50 D bilateral hyperopia simulation (error bars represent the standard error of the mean).