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Correction of Low-Moderate Hyperopia Improves Accommodative Function for Some Hyperopic Children During Sustained Near Work

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Purpose. This study investigated whether refractive correction improved accommodative function of hyperopic children while engaged in two sustained near activities.

Methods. Sustained accommodative function of 63 participants (aged 5–10 years) with varying levels of uncorrected hyperopia (>/= +1.00 D and < + 5.00 D spherical equivalent in the least hyperopic eye) was measured using eccentric infrared photorefraction (PowerRef 3; PlusOptix, Germany). Binocular accommodation measures were recorded while participants engaged in 2 tasks at 25 cm for 15 minutes each: an "active" task (reading small print on an Amazon Kindle), and a "passive" task (watching an animated movie on liquid crystal display [LCD] screen). Participants also underwent a comprehensive visual assessment, including measurement of presenting visual acuity, prism cover test, and stereoacuity. Reading speed was assessed with and without hyperopic correction. Refractive error was determined by cycloplegic retinoscopy.

Results. Hyperopic refractive correction significantly improved accuracy of accommodative responses in both task (pairwise comparisons: t = −3.70, $P = 0.001$, and t = −4.93, $P < 0.001$ for reading and movie tasks, respectively). Accommodative microfluctuations increased with refractive correction in the reading task ($F_{(1,61)} = 25.77$, $P < 0.001$) but decreased in the movie task ($F_{(1,59)} = 4.44$, $P = 0.04$). Reading speed also significantly increased with refractive correction ($F_{(1,48)} = 66.32$, $P < 0.001$).

Conclusions. Correcting low-moderate levels of hyperopia has a positive impact on accommodative performance during sustained near activity in some schoolchildren. For these children, prescribing hyperopic correction may benefit performance in near vision tasks.

Keywords: hyperopia, accommodation, spectacle correction, near work

Uncorrected hyperopia is a common refractive error in childhood.[1,2] The Northern Ireland Childhood Errors of Refraction (NICER) epidemiological study of UK childhood refractive error reported high levels (26%) of hyperopia in 6 to 7-year-old children, defined as +2.00 DS or more of hyperopia using cycloplegic autorefraction.[3] However, hyperopia is likely to remain undetected unless the child attends an eye examination, which includes assessment of refraction. Furthermore, there is poor consensus among clinicians regarding the need for correction of low-to-moderate levels of hyperopia in childhood. As uncorrected hyperopia increases focusing demand on near objects, it is the refractive error most likely to impact on learning through close work. Some children can often adjust their focus (accommodation) to overcome lower magnitudes of hyperopia without correction, but their visual comfort when doing this and the resulting effect it has on reading are poorly understood. If hyperopia is uncorrected, it requires continual accommodative effort to make distance vision clear,[4] and this can impact on the accommodative-convergence interaction during near work. Evidence suggests an association between uncorrected hyperopia and abnormal visual development and poorer academic scores.[5–9] Most school tasks are performed at near working distances, and the prolonged use of electronic devices, such as smartphones, tablets, and e-readers, for both educational and recreational purposes imply that the efficiency of near vision is increasingly more important for the social and educational well-being of children. Although a recent study reported no significant difference between the accommodative response of uncorrected hyperopes and emmetropic children during sustained near tasks, the authors found less stable accommodative responses in uncorrected hyperopia, which may reveal the efforts of the sensorimotor system to achieve optimal response in the hyperopic eye.[10]

Unlike myopia, where optical correction results in significant improvement in distance visual acuity even for low magnitudes of refractive error, the case for hyperopes is not a straightforward one, as measures of neither near nor distance acuity may be compromised. Thus, the question of when to prescribe refractive correction for childhood hyperopia results in considerable inter- and intra-professional differences in ophthalmology and optometry.[11–13] Available evidence to guide prescribing is largely based on consensus and clinician experience. A recent randomized, controlled trial comparing early (at 1–2 years of age) versus delayed intervention for hyperopia failed to find a definitive benefit of early hyperopia correction on the outcome measures of distance visual acuity and near stereoacuity, but the study lacked power in its sample size and the authors acknowledge that further work is required.[14] Data from the Collaborative Longitudinal Evaluation of Ethnicity and Refractive Error (CLERRE) study showed improvement in the accuracy of the accommodative response with optical correction in hyperopia.[15] However, there are a dearth of studies evaluating the relationship between accommodative response and optical correction, particularly during sustained engagement in near work.[5,16,17] Studies that have investigated the accommodative response in connection with uncorrected refractive error have concentrated on the potential for lag of accommodation to be a driver for myopia development.[18–20] The purpose of the present study was to investigate whether accommodative performance of young habitually uncorrected hyperopes aged 5 to 10 years was improved in corrected versus uncorrected refractive conditions during 2 sustained near tasks. The present study also sought to investigate the impact of correction on the reading speed of young hyperopes for a near task.

Materials and Methods

Study Participants

Caucasian children aged 5 to 10 years (n = 134) were recruited from a local primary school, a community optometric practice and the Ulster University Optometry Clinic, in Coleraine, UK. The study was conducted in accordance with the tenets of the Declaration of Helsinki and commenced after approval by the Ulster University Research Ethics Committee. Parental consent was provided for each participant, and a parental questionnaire applied to gain medical and ocular history. Cycloplegic retinoscopy was carried out at the end of the first assessment session using one drop of 1% of cyclopentolate hydrochloride in each eye. Participants were included in the study if their spherical equivalent refraction in the least plus eye after cycloplegic refraction was between >= +1.00 D and < +5.00 D, and they demonstrated anisometropia less than 1.00 D, and astigmatism less than 2.00 DC. Five participants refused cycloplegic eye drops and a further three participants were uncooperative for testing. Participants whose refractive data were outside of these criteria ($n = 43$: of which $n = 37$ were emmetropes, and $n = 6$ were myopic (<= −0.25 D) and/or had significant astigmatism) as well as those with strabismus ($n = 3$) were excluded from further participation in the study. Of the remaining participants with hyperopia ($n = 80$), 17 were excluded for being current ($n = 12$) or previous spectacle wearers ($n = 5$). Therefore, data from 63 uncorrected participants with hyperope are presented in the results. Furthermore, participants with systemic or ocular disease, and medications known to impact on accommodation or the operation of the PowerRefractor 3, as well as those with developmental disorders, which could affect sustained attention, were not recruited into the study. All participants had a comprehensive visual assessment, including presenting binocular distance and near visual acuity (Sonksen crowded LogMAR test at 3 m and 40 cm for distance and near, respectively), stereoacuity (Frisby stereotest), prism cover test, near point of convergence (NPC), amplitude of accommodation (push-up test), and accommodative response (modified Nott retinoscopy). These visual assessments were performed without refractive correction.

Experimental Set-Up

Participants underwent two experimental conditions while they engaged in a reading activity and viewing a movie. In the first experimental condition, participants performed the two tasks without refractive correction. In the second experimental condition, undertaken approximately a week after the first, participants were given their full refractive correction based on cycloplegic refraction results. Cycloplegic refraction was administered after the first experimental condition on all participants. For the second visit, rather than using trial lenses, their refractive correction was glazed into spectacles, and participants adapted to these for 10 minutes prior to testing. Reading speed (Wilkin's Rate of Reading test) was also assessed across the two experimental conditions with and without correction, yielding a measure of words read per minute.

Sustained Near Tasks

Participants undertook 2 tasks in each experimental condition, both of which were performed for a period of 15 minutes: reading text and watching a movie. A 25 cm target distance, reported as a typical near working distance for children in school, was used.[21–23] Before commencement of data collection, preliminary observations showed that there could be high attrition (low completion rates) with the reading task if participants engaged in the movie task first, given the sustained nature of the tasks. Therefore, the protocol commenced with the reading task. However, to assess the possible influence of "order effect" on the outcome of the two tasks, the counterbalancing technique of implementing intervention in an experimental study was introduced in a subgroup of the participants ($n = 4$). This involved reversing the order of assessing the two tasks and getting the participants to perform the movie task before reading. Testing was undertaken at the same time of day each time (in the morning before the participants' lunch break).

Active Task (Literacy Activity)

Participants engaged in a reading aloud activity designed to simulate a visually demanding activity undertaken in school. The task was not meant to assess reading ability, but to engage with a visually demanding near task so to stimulate accommodation. Participants read from an Amazon Kindle presented at a near distance of 25 cm while simultaneous measurement of accommodation, gaze position, and pupil sizes were recorded by the PowerRef 3 photorefraction system. The Kindle, with a viewing window of 14 degrees by 10.2 degrees at 25 cm was housed in a wooden box with a forehead rest. Two Velcro straps around the head of the participant helped to minimize head movements during the task. Prior to testing, the participants' reading ability was evaluated in relation to the choice of age-appropriate reading text available for the assessment. For some younger children (a portion of those aged 5–6 years, n = 19) who

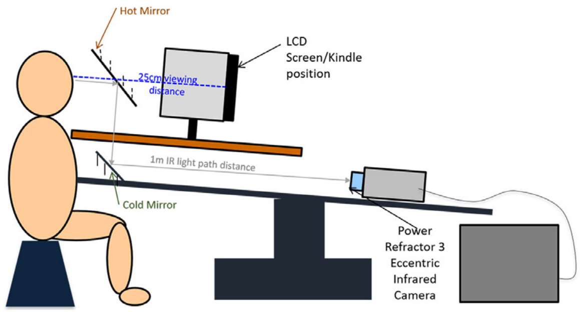


Figure 1. A schematic diagram of operation of the PowerRef 3 infrared photorefraction system, which used two periscopic hot/cold mirrors to reflect infrared light from the instrument's camera aperture into the eye, to enable the reading and movie tasks to be viewed directly on visual axis. The entire table was tilted by 16.7 degrees to enable participants to view in downgaze, thus adopting a more natural reading position.

could not read the simplest reading text, custom-made reading material was designed. The content of the custom-made reading material consisted of high-frequency words used in year 0 (United Kingdom: 4–5 years), and year 1 education (United Kingdom: 5–6 years) alongside pictures that illustrated the word (e.g. the word "cat" with a picture of a cat next to the word). The custom-made material was designed on a series of PowerPoint slides with 5 to 6 words per slide on a portable monitor with a viewing window of 16.70 degrees by 10.20 degrees at 25 cm. A consistent font type (Futura) and size (height of 1.1 mm), was used for all reading material. At a reading distance of 25 cm, the text height corresponded to a visual angle of 0.25 degrees (approximately 6/12 reduced Snellen equivalent). Background illumination for the Kindle and monitor was 40 cd/m^2 and 50 cd/m^2, respectively (measured with ColorCal MK II Colorimeter). The background illumination selected on both the Kindle and monitor provided sufficient contrast while allowing pupil sizes to be maintained within the operational range of the PowerRef 3.

Passive Task (Recreational Visual Activity)

In this task, participants watched an animated movie while simultaneous measurement of accommodation, gaze position, and pupillary response were recorded by the PowerRef 3 at 25 cm. This task was designed to simulate a common recreational activity. The target for the movie task was a popular, commercially available stop-motion animated movie containing broadband spatial frequency content,[24] chosen to engage and sustain interest and attention of participants. The movie target was housed in the same set-up as the reading task (Fig. 1). There was varying background illumination of the target corresponding to the changing scenes during the movie task, with an average background illumination of 30 cdm^2 (range = 10–50 cd/m^2).

Measurement of Sustained Accommodation

Continuous binocular measures of refraction, eye position, and pupil sizes were obtained simultaneously using an infrared photorefraction system (PowerRef 3, PlusOptix, Germany) at a sampling frequency of 50 Hz. A detailed description of the method of photorefraction, from which the PowerRef 3 operates, has been previously reported.[25,26]

The PowerRef 3 camera was mounted on a custom-designed bench at 1 m ± 0.05 m (see Fig. 1) and was designed to ensure optimal comfort for participants while performing the two tasks. The set-up included two periscopic hot/cold mirrors, which were used to reflect infrared light from the instrument's camera aperture into the eye, similar to what has been described in previous work.[24] The entire table was tilted by 16.7 degrees to enable participants to view in downgaze, thus adopting a more natural reading position. The angular subtense adopted in the present study was less than 30 degrees beyond which tilt angle affects reading.[27] A lens calibration routine was performed without correction for each individual to enhance estimates of refraction.[24,28] Where the individual lens calibration estimate was not available, the group average was applied.[24] Prior to participants undertaking the sustained tasks at 25 cm, a baseline measure of refraction, eye position, and pupil size was obtained at 1 m. The difference between the baseline and the 25 cm refractive measures was the accommodative response. The accuracy of accommodation was computed as the difference between the known dioptric demand of 4 D for the 25 cm target and the individual accommodative response measured with photorefraction. See other studies for further description of these methods.[24,29–32]

Data Analysis

Before statistical analyses were undertaken, data from the PowerRef 3 were carefully inspected. Consistent with previous published studies,[24,30,32] data points were excluded if they were outside the operating range of the PowerRef 3 (+5 D to −7 D), outside the horizontal range of the PowerRef 3 for eye position data, and for pupil sizes which were less than 3 mm and greater than 8 mm. These, and data points due to blinks and artifacts, were removed using a custom-written algorithm in MATLAB. For participants who read on the Kindle, data below the 5th percentile and above the 95th percentile in the vertical range were excluded to eliminate data arising from when the participants were reading the top and bottom of the page of text, as this up and down gaze could affect measurements (Fig. 2B). These outliers could have contaminated the results and were therefore winsorized.[33] These outliers were not produced when the participants read centrally placed text on the liquid crystal display (LCD) or during the movie task.

The accuracy and stability of the accommodative responses were analyzed. The characteristics of the accommodative response were analyzed using the average of all data samples within each minute (60 seconds of data, approximately 3000 samples) across the 15-minute time period and the average of these values indicated the subject's accommodative response for each test condition.[34] This approach was adopted after visual inspection of data (see Fig. 2B), and repeated measure ANOVA analysis of the 1-minute segments (using the reading task data) revealed that the accommodative response did not differ significantly over time in individual subjects ($F_{(11,653)} = 1.82$, $P = 0.09$). The stability of the accommodative response was analyzed using the root mean square error (RMSE) of accommodative microfluctuations.[30,35] Although accommodation was measured for each eye, the data from the least hyperopic eyes were used to determine accommodative response. Participants were categorized as low hyperopes (+1.00 D to less than +2.00 D) and moderate hyperopes (+2.00 D to less than +4.50 D).[2,36,37]

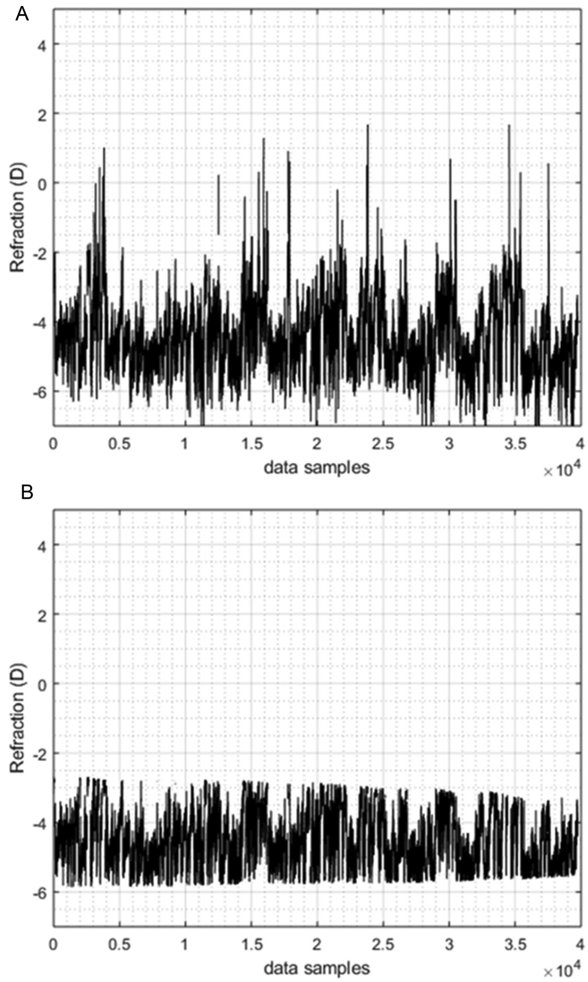


Figure 2. (**A**) An example of the accommodative response over time in the reading task showing apparent variation in response when participant was reading the top and bottom of the Kindle screen, in up and down-gaze positions. (**B**) The same accommodative response after data points corresponding to these outliers in panel **A** were removed. The Y-axis represents refraction (from which the accommodative response was computed), and the X-axis represents the length of the data samples (from which the duration of measurement can be derived, given the 50 Hz sampling frequency of the PowerRef 3).

The effect of optical correction on the accommodative response (treatment outcome) was considered "positive" if correction increased the accuracy of the mean response where there was a lag of accommodation or reduced the mean response where there was lead of accommodation of at least 0.50 D. A "negative" effect was defined as decreased accommodative accuracy by at least 0.50 D with correction, and the correction was deemed to have "no effect" on accommodative response when there was less than 0.50 D difference between uncorrected and corrected measures. The value of 0.50 D was chosen, as this within the repeatability limits of the PowerRef 3 and subjective refraction.[38]

Analysis of variance and covariance (ANOVA and ANCOVA) were used to assess the effect of optical correction on the accuracy and stability of the accommodative response, and the rate of reading test results. During each statistical testing, the covariate was the measure without correction. Statistical significance was set at $P < 0.05$.

Results

All 63 hyperopic participants cooperated with testing without correction while performing the 2 sustained near tasks; and 62 (98%) and 60 (95%) of subjects were available during follow-up testing with correction in the reading and movie tasks, respectively. The mean age of participants was 7.75 ± 1.66 years. The spherical equivalent refraction for the least plus eye of participants ranged from +1.00 D to +4.38 D; none had clinically significant astigmatism greater than −0.50 DC. The majority of participants were orthophoric (no movement detected on cover test) at distance and near (98% and 62% for distance and near, respectively). At near, the 38% of participants with heterophoria all had deviations less than 10 prism diopters. Other descriptive statistics of accommodative response (accuracy and stability) are presented in Table 1.

Effect of Hyperopic Refractive Correction on the Accuracy of Accommodative Response

There were significant main effects of treatment outcome in the reading and movie tasks ($F_{(2,61)} = 17.06$, $P < 0.001$) and $F_{(2,59)} = 27.82$, $P < 0.001$) for reading and movie tasks, respectively. Pairwise comparisons using Bonferroni, revealed that refractive correction significantly increased the accuracy of the accommodative response in "positive" responders in the reading ($t = -3.70$, $P = 0.001$) and movie tasks ($t = -4.93$, $P < 0.001$). Moreover, the observed effect of correction on the accommodative response occurred across the spectrum of hyperopia magnitude ($F_{(1,61)} = 1.76$, $P = 0.19$, and $F_{(1,59)} = 0.99$, $P = 0.33$) for reading and movie tasks, respectively.

To determine whether differences existed between subjects whose accommodative accuracy improved with correction ("positive" responders) and those who did not ("negative" responders and "no effect" groups), a Kruskal-Wallis test was conducted to determine whether participants differed in terms of their baseline near visual function measures, such as near acuity, stereoacuity, and lag of accommodation (Table 2). There was no significant difference in any of the underlying visual measures between participants who responded positively to correction and those that did not.

Effect of Hyperopic Refractive Correction on the Stability of Accommodative Response

There was an increase in accommodative microfluctuations with correction in the reading task ($F_{(1,61)} = 25.77$, $P < 0.0001$, 3-way ANCOVA; Fig. 3A). However, in the movie task, there was decreased microfluctuations with correction ($F_{(1,59)} = 4.44$, $P = 0.04$; Fig. 3B). In both tasks, there was no influence of age on results (all $P > 0.05$). Pairwise comparison using Bonferroni correction, revealed that significant effects were mainly observed in participants in the +2.00 to < +4.50 D group ($t = 2.50$, $P = 0.028$, and $t = 2.20$, $P = 0.032$ for reading and movie tasks, respectively). There was a weak but significant correlation between the RMSE of accommodative microfluctuations and the mean accommodative response measured with correction in the reading task ($r = 0.25$, $P = 0.04$). However, this was not found for the movie task ($r = 0.18$, $P = 0.16$).

Table 1. Mean (SD) Accommodative Response (Accuracy and Stability) for the Reading and Movie Tasks for Participants With and Without Their Hyperopic Correction in Place

	Accommodative Response, Accuracy		Accommodative Response, Stability	
Reading Task, Active	**Mean ± SD (Without Correction)**	**Mean ± SD (With Correction)**	**Mean ± SD (Without Correction)**	**Mean ± SD (With Correction)**
Overall, $n = 63$	**2.99 ± 0.87 D**	**2.82 ± 1.04 D**	**0.21 ± 0.13 D**	**0.24 ± 0.12 D**
Hyperopia ≥+1.00 to <2.00 D, $n = 38$	2.89 ± 0.75 D	2.62 ± 0.74 D	0.20 ± 0.11 D	0.22 ± 0.10 D
Hyperopia ≥+2.00 to <4.50 D, $n = 25$	3.17 ± 1.01 D	3.13 ± 1.35 D	0.22 ± 0.15 D	0.29 ±0.12 D
Group difference	t = −1.28, $P = 0.20$	t = −1.96, $P = 0.06$	t = −0.74, $P = 0.46$	t = −1.91, $P = 0.06$
Movie task, passive				
Overall, $n = 63$	**2.34 ± 0.82 D**	**2.35 ± 1.01 D**	**0.29 ± 0.13 D**	**0.21 ± 0.11 D**
Hyperopia ≥+1.00 to <2.00 D, $n = 38$	2.23 ± 0.69 D	2.17 ± 0.85 D	0.26 ± 0.11 D	0.18 ± 0.09 D
Hyperopia ≥+2.00 to <4.50 D, $n = 25$	2.50 ± 0.98 D	2.64 ± 1.20 D	0.33 ± 0.16 D	0.25 ± 0.12 D
Group difference	t = −1.26, $P = 0.21$	t = −1.76, $P = 0.08$	t = −2.42, $P = 0.02$	t = −2.71, $P = 0.01$

The accuracy was determined as the mean response to a 4 D target during the 15-minutes of testing, whereas the root mean square error of the mean response over the 15-minutes of testing represents the stability. Classification of hyperopia was determined by mean spherical equivalent of the least plus eye.

Table 2. Distribution (Median, 25th, and 75th IQR) of Near Baseline Visual Measures (Without Correction) in Participants According to Their Treatment Outcome

Reading Task Refractive Classification By Treatment Group	**Near VA, LogMAR Median (IQR)**	**Stereoacuity, Seconds of arc Median (IQR)**	**Accommodative lag (D) Median (IQR)**	**Rate of Reading Score, Words Per Minute, Median (IQR)**
Positive	0.00 (0.00 to 0.13)	40 (20 to 55)	0.29 (0 to 0.49)	91 (89 to 102)
1 to < 2.00 D, $n = 8$				
2 to < 4.50 D, $n = 7$				
Negative	0.00 (0.00 to 0.03)	30 (20 to 75)	0.23 (0 to 0.55)	97 (81 to 105)
1 to < 2.00 D, $n = 15$				
2 to < 4.50 D, $n = 9$				
No effect	0.00 (0.0 to 0.15)	40 (20 to 55)	0.30 (0.15 to 0.77)	87 (74 to 99)
1 to < 2.00 D, $n = 15$)				
2 to < 4.50 D, $n = 8$)				
Group difference	H = 1.29, $P = 0.52$, df = 2	H = 0.42, $P = 0.81$, df = 2	H = 1.21, $P = 0.55$, df = 2	H = 2.88, $P = 0.24$, df = 2
Movie task				
Refractive classification by treatment group				
Positive	0.00 (0.00 to 0.08)	40 (25 to 75)	0.00 (−0.16 to 0.49)	91 (74 to 101)
1 to < 2.00 D, $n = 8$				
2 to < 4.50 D, $n = 8$				
Negative	0.00 (0.00 to 0.00)	30 (20 to 55)	0.30 (0 to 0.77)	90 (75 to 102)
1 to < 2.00 D, $n = 11$				
2 to < 4.50 D, $n = 7$				
No effect	0.00 (0.00 to 0.03)	30 (20 to 40)	0.23 (0.00 to 0.55)	87 (81 to 103)
1 to < 2.00 D, $n = 18$				
2 to < 4.50 D, $n = 8$				
Group difference	H = 0.94, $P = 0.63$, df = 2	H = 1.56, $P = 0.46$, df = 2	H = 3.90, $P = 0.14$, df = 2	H = 0.06, $P = 0.97$, df = 2

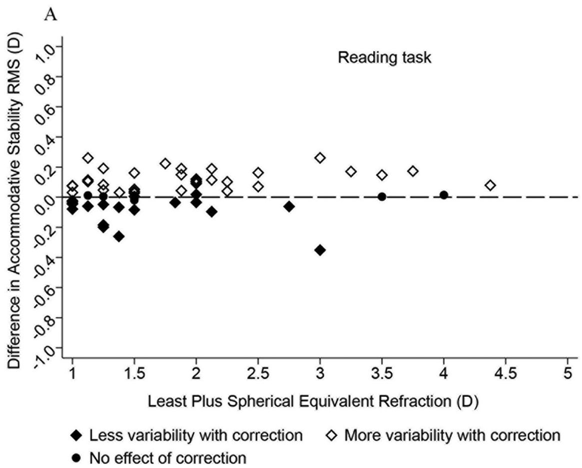
Group difference was assessed using the Kruskal-Wallis test.
IQR, interquartile range; VA, visual acuity.

Effect of Refractive Correction on the Rate of Reading Score

The mean rate of reading score with and without correction was 90.98 ± 22.34 and 88.00 ± 22.30 words per minute, respectively. Hyperopic correction significantly increased the rate of reading score (3-way ANCOVA test, $F_{(1,48)} = 66.32$, $P < 0.001$; Fig. 4). This finding was independent of the magnitude of refractive error present ($F_{(1,48)} = 0.16$, $P = 0.69$) or participant age ($F_{(1,48)} = 4.21$, $P = 0.05$). However, there was no significant difference in rate of reading score by treatment outcome (Kruskal Wallis H = 0.64, $P = 0.73$, df = 2). In the literature, a clinically significant difference in rate of reading score is considered as an increase of 5%.[39,40] In the current study, the mean percentage improvement in reading speed with correction was 3.7% ± 15.0%. Again, considering this by treatment outcome, there was no significant difference in increase in reading speed by percentage change across groups (Kruskal Wallis H = 0.85, $P = 0.65$, df = 2).

Discussion

The potential benefit of correcting moderate hyperopia in childhood is a significant gap in our current knowledge, and an important issue to address to enable clinicians to recognize when intervention has the potential to optimize visual function. The present study addressed this knowledge gap, investigating the effect of optical correction on sustained accommodation in previously uncorrected



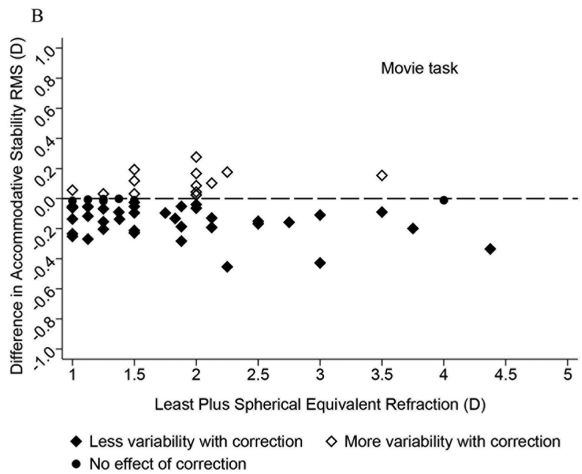


Figure 3. (**A**) Effect of hyperopic refractive correction on the stability of the accommodative response in the reading task, calculated as the difference between the root mean square error (RMSE) of the accommodative response with and without correction. (**B**) Effect of correction on the stability of the accommodative response in the movie task, calculated as the difference between the RMSE of the accommodative response with and without correction. The long-dashed line represents no effect of correction (difference of zero). Data points above *long-dashed line* represent more accommodative response instability with correction, while those below line represents less instability with correction.

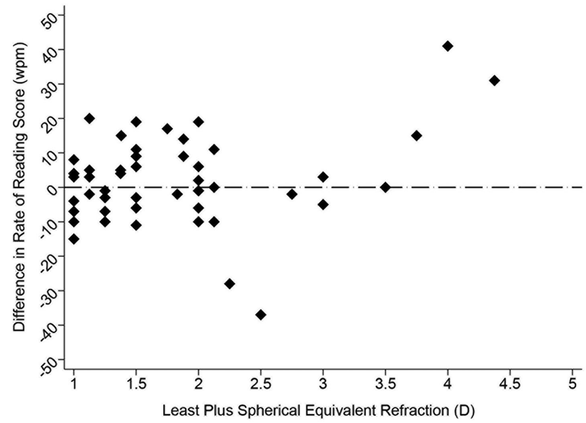


Figure 4. Improvement in reading speed with hyperopic refractive correction. This was calculated as the difference between the reading speed score with and without correction. *Long-dashed line* represents no effect of correction (difference of zero). Data points above line represent improvement in reading speed with correction.

hyperopes of school-age while engaged in relatively prolonged periods of near vision activity.

Results of the present study indicate that refractive correction improved the accuracy of the accommodative response in some hyperopes in two near vision tasks (reading text and watching a movie), reducing lags/leads of accommodation that had been recorded without correction. To correct underlying refractive error and focus on a given target, uncorrected hyperopes tend to exhibit greater accommodation for a given distance compared to their emmetropic or myopic counterparts.[10] The additional effort implemented to achieve clear vision may be associated with eye strain and visual discomfort, which could be due to the interplay between the accommodative and vergence systems. A 0.50 D improvement in the accuracy of accommodation may be considered clinically significant enough to influence a clinician to prescribe spectacle correction. The positive effect of refractive correction on the accuracy of accommodative response was observed across the spectrum of hyperopia included in this study. The observed effect of correction on accommodative performance was also independent of participant age. Although some previous studies have reported improvement in the visual functions and academic performance of some individuals when hyperopia is corrected,[15,41,42] it is not currently clear whether the visual profile of those who respond to such treatment are comparable to those who do not. The visual characteristics of hyperopes who are likely to benefit from optical correction are poorly understood, and thus there are no agreed clinical indicators for prescribing a hyperopic refractive correction.[9] Against this background, the present study sought to differentiate between hyperopes who had "positive" outcomes with optical correction and those who did not, on the basis of their visual characteristics, such as near visual acuity and stereoacuity. However, baseline visual characteristics (see Table 2) between subjects in the present study who responded positively to spectacle correction (improved accuracy of accommodation) did not significantly differ from those whose accommodative accuracy was not improved with correction. Furthermore, there was no difference in amplitude of accommodation across treatment outcomes, and participants' ocular posture at far and near were either orthophoric or demonstrated a small magnitude of phoria with rapid binocular recovery.

Despite a breadth of measures, the choice of visual metrics included in baseline measures may have been too restricted and/or their outcomes too gross to differentiate between hyperopes whose accommodative function would or would not improve with optical correction. It is possible that an assessment of these measures with correction would help identify children who benefit most from correction. The fusional vergence range may also be valuable to measure.

There are very few studies that have investigated accommodative performance over a sustained period of time. Uniquely, this study investigated performance in two sustained (active and passive) near activities undertaken for 15 minutes each. It is interesting to note that uncorrected hyperopes did not exhibit a deterioration in accommodative response over time in these tasks.

Accommodative microfluctuations represent steady-state variability in the accommodative response.[43] Although their exact role in the accommodative response control is yet to be fully understood, current consensus is that microfluctuations serve as an "error" cue to quantify the magnitude and direction of the mean defocus level to help maintain appropriate accommodative responses.[30,43,44] Microfluctuations increase with increasing mean accommodative response. Results of the present study indicate that there were increased accommodative microfluctuations associated with refractive correction during the reading task, but the reverse finding was observed in the movie task. Moreover, in the reading task, increased variability in the accommodative response with refractive correction was associated with increased magnitude of accommodative response, although the observed association was weak. It is unclear why there was inter-task difference in the effect of correction on microfluctuations. Across the two tasks, when participants were tested without correction (see Table 1), differences in microfluctuations were observed with increased microfluctuations in the movie task (t = −3.53, $P = 0.001$). Data from the emmetropic participants ($n = 37$), which were obtained during the process of finding hyperopic participants, showed similar trend in inter-task differences in microfluctuations (0.24 ± 10 D vs. 0.20 ± 0.10 D for movie and reading tasks, respectively, although it did not reach significance (t = −1.88, $P = 0.07$). However, beyond any inherent inter-task differences in target characteristics, it would have been expected that with full correction of hyperopia, the extra accommodative demand due to uncorrected hyperopia would have been eliminated, thus reducing the activity of the accommodative plant (crystalline lens movement), resulting in a more stable accommodative response; which is consistent with the results obtained in the movie task. Nonetheless, the correlation between the RMSE of accommodative variability and the mean accommodative response during the reading task also suggests that perhaps with spectacle correction, microfluctuations of accommodation increased as a way of providing temporal directional sign for the accommodative controller to produce an appropriate response.[43] It is also possible that correction of hyperopia increases the sensitivity of the sensorimotor system (accommodative system) to maximize error detection, thus resulting in more fluctuations concurrent with increased accommodative response.[45]

The results of the present study show that hyperopic refractive correction improved reading speed in our participants, although the magnitude of difference was modest and not significantly different across treatment outcomes. Despite methodological differences, this result is consistent with the findings of van Rijn et al.[41] who investigated the role of refractive correction in reading speed of young hyperopes (aged 9–10 years). Perhaps hyperopic refractive correction allows clearer near vision to be achieved, promoting more fluent reading by some corrected hyperopes. The present study also shows that this observed positive effect of refractive correction on reading speed was not limited by the magnitude of hyperopia, suggesting that even low amounts of uncorrected hyperopia may benefit from improved reading speed with correction. This finding is unlikely to be influenced by astigmatism, given that the magnitude of astigmatism of participants in the present study was insignificant (less than −0.50 DC).

Given the limited evidence of benefit related to the correction of low-moderate levels of hyperopia, there is a trade-off between the ethical implications of conducting a long-term wear intervention trial, and an evaluation of the immediate impact of correction. The present study design corrected hyperopic refractive errors using bespoke glazed spectacles in the second experimental visit, and participants underwent testing after a brief adaption period. Although many studies have investigated the effects of positive trial lenses during short-term evaluation,[18,46,47] the long-term effect of correction is yet to be determined. However, given that these visual effects were observed during closed-loop testing conditions, the potential for these effects to disappear with long term adaptation (e.g. due to tonic adaptation, which occurs under monocular viewing conditions) is less likely.[46]

A recent study reported that photorefractive estimates of refractive error/accommodation made through spectacle lens correction could underestimate the magnitude of refractive error due to image magnification of the luminance profile in the pupils.[48] The authors further report that this effect is compounded by large vertex distances. However, in the present study, constant vertex distance (12 mm) while wearing spectacles was checked and maintained by fixing adhesive nose pads on the spectacles of each participant, thus minimizing effects from variable vertex distance. Additionally, the range of lenses used (mostly +1.00 D to +4.00 D), and the small vertex distance (12 mm) would not give rise to significant magnification effects, with a +4.00 D lens reported to give rise to less than 0.25 D of additional accommodation due to lens effectivity.[33]

There may be concerns about the Hawthorne effect bias due to participants' awareness of undertaking the tasks without correction first, and later with correction. The study would thus have benefitted from a double-blind cross-over design with all participants wearing either placebo spectacles or spectacles with refractive correction.

Although the present study used the relative lens calibration routine to reduce variability in the luminance slope change per diopter of induced defocus in subjects, the lack of absolute calibration (e.g. simultaneously comparing the PowerRef 3 measures with Nott retinoscopy) presents a limitation in the estimation of lag. However, a previous study suggested a good agreement between an earlier version of the PowerRef 3 (PowerRef II, Multichannel systems) and retinoscopy during an absolute calibration.[49] Importantly, lag was estimated as the relative change in accommodation at 1 m and 25 cm, which should minimize the effects of lack of absolute offset.

This work is the first to demonstrate the benefit of correcting low-moderate levels of hyperopia on accommodative performance and reading speed for sustained near activity in schoolchildren. It also highlights the value of assessing visual functions beyond acuity and stereoacuity, such as vergence and accommodative amplitudes, and visual function testing with and without correction to fully understand near vision performance. Future work should investigate the longer-term clinical and educational benefit of prescribing hyperopic corrections to optimize the accommodative response.

Conclusion

Our results indicate that for some children with low to moderate hyperopia, optical correction optimizes accommodative function during sustained near activities. Hyperopic refractive correction also improves reading speed in a subgroup of hyperopic children and, if shown to be a sustained improvement, this could be an important consideration in relation to scholastic achievement.

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