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Binocular adaptation to +2D lenses in myopic and emmetropic children

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Abstract

Purpose: To compare vergence adaptation to +2D addition lenses in myopic and emmetropic children and to evaluate the influence of the accommodative-vergence cross link (AC/A ratio) on this adaptation.

Methods: 9 myopic and 11 emmetropic children fixated a near target at a distance of 33 cm. Measures of binocular and monocular accommodation and phoria were obtained during a 20 minute near task with and without +2D lenses. Response AC/A ratios were determined from the experimental results. Vergence adaptation was quantified by the magnitude of phoria reduction and the percentage of completeness (PC, return of adapted phoria to habitual level) after the near task.

Results: Myopic children showed significantly higher AC/A ratios which led to greater lens-induced exophoria and a greater demand for vergence adaptation. Both refractive groups showed significant vergence adaptation; however, myopes exhibited significantly reduced ($P<0.01$) magnitudes compared to emmetropes (Myopes= 3.95±0.15Δ, Emmetropes =4.41±0.08Δ). The mean PC was also significantly ($P< 0.001$) reduced in myopes (61.02±1.57) compared to emmetropes (76.6±2.10). There was a significant correlation between magnitude of adaptation and AC/A in both the refractive groups; however, myopes consistently showed reduced magnitudes compared to emmetropes. AC/A ratio influenced PC in emmetropic but not myopic children. In the accommodation system, +2D lenses eliminated the accommodative lags observed in myopic children during natural viewing conditions. These lenses resulted in a small over-focus (-

0.24±0.27D) at the onset of near work, which decreased during sustained viewing through the near add.

Conclusion: Myopic children demonstrate reduced magnitude and completeness of vergence adaptation to +2D lenses. The magnitude of vergence adaptation varied with AC/A in both refractive groups; however, the presence of myopia differentiated the size of adaptation. On the other hand, degree of completeness appears to be primarily associated with the type of refractive error.

Keywords: Myopia; near addition lenses; vergence adaptation; accommodation; near phoria

Introduction

Near addition lenses have been prescribed to myopic children in an attempt to slow the progression of myopia attributed to near work. [1-5] The current basis for prescribing near adds to myopic children is to eliminate the large accommodative lags [6] that might create a hyperopic retinal defocus and possibly trigger axial elongation of the eye. [7-9] Clinical trials that evaluated the ability of these lenses to slow myopic progression provided varying results ranging from no success, [10, 11] limited success [12, 13] to clinically significant reduction of myopia. [14, 15] Several studies have shown that myopic children with esophoria display greater benefit (i.e. less progression of myopia) from wearing near adds compared to children with exo or orthophoria. [13, 16, 17] In addition, accommodative responses seemed to influence myopia progression through the near add, with the greatest reduction of myopic progression observed in children with larger accommodative lags [13,16] and in esophoric children with higher lags of accommodation. [18] These findings suggest that the accommodative and phoria status of the child might play a significant role in the mechanism of reduction of myopic progression with plus lenses.

Several studies have evaluated the effect of near adds on the accommodative responses of emmetropic [19-22] and myopic adults. [23] These investigations consistently show that plus lens additions are capable of reducing the lag of accommodation at low dioptric powers (+1D) [19,20] and result in a small amount of over-focus or lead of accommodation with higher dioptric powers (+2 and +3D) [20- 22] Past research shows evidence for greater accommodative lags in myopic children under negative-lens induced monocular viewing conditions, [6, 24] with monocular real targets [25] or under binocular viewing condition through full refractive correction. [26] However, relatively few investigations have evaluated the ability of near adds to reduce or eliminate the accommodative lags observed in myopic children.

In the vergence system, studies have evaluated the effect of near adds on adult participants, either immediately after the addition of lenses [23] or with sustained fixation. [27,28, 29] It is known that near adds affect both accommodation and vergence through the accommodative vergence (AV) (Mueller 1826, cited in Alpern [30]) and vergence-accommodation (VA) [31]cross links. However, earlier investigations did not measure coincident changes to both systems but measured changes to either accommodation or vergence alone. [19-21, 29] A recent study from our group evaluated the coincident time course of changes to accommodative response and near phoria when emmetropic adults' sustained fixation (33 cm) through +2D lenses. [22] A consistent pattern of change was observed. Introduction of near addition lenses produced an exophoric shift, accompanied by a significant increase in binocular accommodation over that of monocular accommodation. This difference, (attributed to convergence accommodation), was believed to be a result of the lens-induced exophoria triggering an increase in fast reflex convergence and subsequently an increase in the output of convergence driven accommodation.[32-34] After several minutes of prolonged viewing, vergence adaptation occurred, concurrently reducing the exophoria and the binocular levels of accommodation while monocular levels remained constant. The degree of vergence adaptation was quantified using two parameters. The first parameter, magnitude of adaptation, represents the absolute change in phoria through +2D adds before and after the near task. The second parameter, percentage of completeness (PC) describes the degree to which the phoria has returned to its original level prior to viewing through the near add. Past studies on prism adaptation commonly quantified adaptation as a change in induced phoria only

[35-40] similar to our first parameter, the magnitude of adaptation. We found that a second term, PC was necessary because the lens induced change in phoria was not the same for each subject but rather it depended on their AC/A. Therefore, any two individuals showing the same magnitudes of adaptation will not exhibit the same PC of adaptation if they have different AC/A ratios. In our previous study, both magnitude and completeness of vergence adaptation were dependent on an individual's AC/A ratio. [22] Higher AC/A ratios were associated with greater magnitudes of adaptation but the lens-induced exophoria did not return to its habitual level indicating less-than complete vergence adaptation.

Past studies show higher response AC/A ratios in myopic children compared to emmetropes [41,42]. Based on the results from our adult study [22] it can be hypothesized that near addition lenses will produce greater exophoric shift that would increase the fusional vergence demand in myopic children. This increased vergence demand, in turn, will require greater levels of vergence adaptation if the lens-induced phoria is to return to its original level. In addition, myopic children might not exhibit the same magnitude of accommodative lead seen in emmetropic adults due to the larger accommodative lags observed under binocular [26] or monocular viewing conditions.[6, 24, 25] Relatively few investigations have evaluated the changes to both accommodation and vergence response when myopic children perform near task through plus addition lenses. Recently, Cheng and co-workers evaluated the effect of various combinations of positive lens additions and base-in prisms on the accommodative lag and near phoria of progressive myopic children. [43] The authors measured the responses immediately after the addition of lenses / prisms and concluded that the combination of +2.25D lens and 6 $^{\Delta}$ base-in resulted in minimal accommodative lag and exophoria. However, as acknowledged by the authors, this investigation did not measure changes to accommodation and phoria during sustained near activity. Thus, the possibility of vergence adaptation to lenses and prisms cannot be excluded and the beneficial effect of reduced phoria and accommodative lag may not be maintained over a period of prolonged spectacle wear.

To our knowledge, vergence adaptation to near addition lenses has not been investigated in myopic children. North and colleagues compared adaptation to 6 $^{\Delta}$ base-in and base-out in adult groups of emmetropes, early onset and late onset myopes. [37] They reported no difference in the magnitude of prism adaptation between the three refractive groups. On the other hand, Rosenfield suggested that late onset myopes might have reduced vergence adaptive ability compared to emmetropes. [44] Therefore, it is still not clear whether the adaptive ability of young myopes is any different from that of emmetropes. Thus, aim of this study was to investigate the time course of changes to accommodation and vergence when myopic children perform sustained near work (20 min) through +2 D addition lenses. Based on the results of our adult study [22] and the higher AC/A ratios expected in myopic children [41, 42] we hypothesize that myopic children may show less complete adaptation to near adds compared to emmetropes. We will explore the extent to which the AC/A ratio accounts for the differences in adaptation.

Methods

Study participants

Twenty-three children (ten myopic and thirteen emmetropic) between the ages of 7 and 14 years were recruited from the clinic database at the School of Optometry, University of Waterloo. The protocol followed the tenets of the Declaration of Helsinki and received approval from institutional review board. Informed consent (parents) and assent (children) were obtained after verbal and written explanation of the nature and possible consequences of the study.

Participants with normal general and ocular health (determined from their clinical records) underwent preliminary examination to ensure the following: myopic refractive error between -0.75 and -6 D or emmetropic refractive error between +0.5 and +1.5 D determined using cycloplegic refraction; astigmatism < 1D; anisometropia < 0.5D; best corrected visual acuity of at least 6/6 in each eye; normal binocular vision status ensured through normal distance and near phorias [45] by prism neutralized cover test; normal amplitudes of accommodation; and that participants were not taking any medications that might influence the accommodation and vergence systems. [46] Table 1 lists the age and critical visual parameters of the two study groups.

<INSERT TABLE 1 HERE>

Instrumentation and experimental procedure

The instrumentation and the experimental setup used in this study have been described in detail elsewhere. [22] Briefly, accommodative responses were obtained when children fixated a single high contrast (85%) color cartoon frame at a distance of 33cm. This target was chosen as it was expected to be more successful than conventional reading material in holding the participants' attention. Accommodative responses with and without +2D lenses were obtained using the *monocular mode* of an eccentric infra-red (IR) photorefractor (PowerRefractor, MultiChannelSystems, Reutlingen, Germany for description see [47, 48]) at a sampling rate of 25 Hz for a period of 10 sec. When tested with near addition lenses, the PowerRefractor recorded accommodative measures as a sum of the near addition lens and the accommodative response. This combination, conjugate with the participants' retina was termed *"plane of focus"*. [22] Thus, in the no add condition; the plane of focus approximates the participants' accommodative response given that myopes were corrected for their distance vision. When viewing through the near add the plane of focus would correspond to the combination of +2D lens and accommodative response through the lens. "Binocular plane of focus" was measured while both eyes fixated the target; however, responses were recorded from the right eye alone. For the measurement of "monocular plane of focus", the left eye was occluded. During the 10 sec measurement period, the accuracy of fixation was assessed using the gaze control function displayed on the PowerRefractor interface. Additionally, care was taken to ensure that the child was fixating the near target at the correct fixation distance (33 cm) while measurements were recorded. A volunteer constantly monitored the head position of the child and ensured they did not move away from the chin rest during measurement. If unsteady fixation was noticed during measurement, or when the examiner (VS) observed off axis gaze errors exceeding 5 degrees, the measures were flagged using keyboard inputs and discarded given the possibility of under or over estimation of accommodation. [49-52] In these cases, recordings were obtained for an additional 5 sec period to ensure equal data sets across subjects. In addition, measures of open loop accommodation (tonic accommodation) were taken by instructing participants to monocularly fixate (left eye occluded) a low spatial frequency (0.2 cpd) difference of Gaussian target placed at a distance of 3.5 meters.

Accommodative measures obtained from the PowerRefractor were calibrated using a protocol similar to previous studies. [20, 22, 53] Briefly, the output of the photorefractor was compared to actual levels of refractive error induced on each participant by the addition of ophthalmic trial lenses (-1D to +6D). From this procedure, calibration formulae were defined for each of the two groups. The absolute precision of accommodative response was then determined by comparing the PowerRefractor response with dynamic retinoscopy when participants viewed a near target (33cm). Based on the results of the calibration study all Power Refractor responses (PR) from both refractive groups were adjusted using calibration equations (see below) to define actual plane of focus response (PF)

Myopes: $PF = (PR / 1.12) - 0.22$ (1)

Emmetropes: $PF = (PR/1.07) - 0.25$ (2)

Though the two equations show slightly different slopes, this difference was small and was not found to be statistically significant ($P>0.2$). Moreover, the accommodative responses did not differ significantly when individual calibration equations were used instead of group equations in both refractive groups (Margin of error <0.10D; $P >0.6$).

Horizontal near heterophoria (33cm) was measured using the modified Thorington technique (MTT) and the magnitude of the phoria was quantified using a custom designed tangent scale. This technique showed good validity and repeatability in previous studies [54-57] The efficacy was also confirmed from our own experience where we have found the 95% limits of agreement with cover-test to be $\pm 1.02\Delta$. The co-efficient of repeatability between measures taken on two different days was observed to be 1.98Δ (1.96*standard deviation of difference). [22] The tangent scale used to quantify phoria consisted of a small central aperture for the light source and a horizontal row of letters/numbers on either side with each letter/number separated by 3.3

mm (1Δ apart at a distance of 33cms). A red Maddox rod was placed before the right eye and phoria was measured using a "flashing technique" similar to previous studies. [22, 29] The participants verbally reported the number/letter that was closest to the red line. The same technique was repeated thrice and near heterophoria was defined as the average of the three responses. Considering the possibility of higher variability in this age group, all children received a training session with the MTT prior to the experimental session. During the training session, picture cards were shown to facilitate better understanding of the test. Near phoria was measured 5 times and all children were able to achieve standard deviation of less than 1.5 Δ (range 0-1.25 Δ; mean = 0.51 ± 0.43). The variability of phoria response within the experimental session (i.e. the variability between the three trials obtained during a particular time point) was also determined at each time point tested in the study. The highest mean (±SD) variability was observed to be 0.50±0.53Δ in our study group.

The experimental procedure consisted of two study sessions; one session was performed with the children wearing their corrective lenses if any in a trial frame (referred to as *"no add condition"*) and the other involved measurements with +2D lenses (referred to as *"add condition"*) added over their correction (if applicable). The +2D lenses were inserted at a distance of 12 mm from the participants' eyes and the trial frame was adjusted for the participants near pupillary distance so as to reduce any prismatic effect. The two study sessions were performed on different days (separated by at least by 24hrs) and the order of testing was randomized to avoid bias. Prior to the start of the study sessions, all participants were dark adapted for 3 minutes to avoid effects of previous near work. [58] The lighting in the examination room was then reduced to approximately 10 lux to obtain sufficiently large pupil sizes (greater than 4mm as recommended by the manufacturer of PowerRefractor) for the measurement of accommodation. Each session involved measurement of pre-task tonic accommodation (open loop accommodation immediately after dark adaptation), followed by baseline measurement of phoria (vergence open loop), binocular and monocular plane of focus (closed loop accommodation). The approximate time taken for one complete measurement block (measurement of phoria, binocular and monocular focus) ranged between 1 and 1.5 min. Following the baseline measurement, participants were instructed to watch a cartoon movie that was played at a distance of 33 cm. This target was chosen to avoid boredom and to ensure sustained near fixation for the scheduled duration of the study (20 min). Subsequent measures of phoria, binocular and monocular plane of focus were then recorded after 3, 6, 9, 15 and 20 minutes of near fixation. Plane of focus measures were taken at the above mentioned time points by replacing the movie clip with the single frame (cartoon slide) used in the baseline measurement in an attempt to keep the illuminance of the target constant. Post-task tonic accommodation was finally measured after the 20 minute near task.

Data Analysis

The plane of focus response at each time point was estimated by averaging the data points obtained over the measurement period (normally 10 sec) similar to the method described in our previous study. [22] Briefly, each data point was screened and accepted if the following criteria were met: the pupil size was above 4mm (as per PowerRefractor manufacturer guidelines); the horizontal and vertical deviations in gaze were less than 5 degrees from the center of the camera; and the responses were free of blinks (blink artifacts removed by a method similar to our previous study [22]). To be considered for averaging and further analysis, each participant needed to have at least 200 rows of acceptable data after satisfying all of the above criteria. If the participants had more than 200 eligible data points, only the first 200 points were taken for further analysis. The data retained were averaged to obtain the plane of focus response for a particular time point. Three study participants were excluded from the averaging process since they failed to provide the minimum levels of acceptable data as a result of pupil diameters less than 4mm (1 emmetrope and 1 myope) and excessive gaze deviation (1 emmetrope). Thus the data of 11 emmetropes and 9 myopes were considered for further analysis.

In order to quantify the effect of the accommodative-vergence cross link (AC/A) on the vergence response with +2D lenses, stimulus and response AC/A ratios of all participants (N = 20) were determined from the experimental results (with +2D lenses) using the Gradient AC/A method. The change in phoria responses were then studied based on the magnitude of AC/A ratio.

Repeated measures analyses of variance (RM-ANOVA) was used to determine the effect of lens condition and time on plane of focus and vergence. In all cases, statistically significant main effects were further examined using Tukey Honestly significant differences (HSD) post-hoc tests to determine the precise time point that showed the significant difference. Differences were considered statistically significant when the likelihood of type-I error was <0.05. Data analysis was performed using STATISTICA 6.0 (StatSoft, Inc, USA). Exponential curve fitting and analysis were performed using Graphpad software (Graphpad Inc, USA) to investigate the changes in near phorias through +2D lenses.

Results

Changes to plane of focus measures without near add and with +2D lenses

The dotted lines in Fig. 1 shows the plane of focus measures during the no add condition from emmetropic (Fig. 1A) and myopic (Fig. 1B) children. Myopic children exhibited significantly greater accommodative lags (denoted by negative sign) compared to emmetropes under binocular and monocular viewing conditions (binocular viewing: Emmetropes = -0.60 ±0.06D; Myopes = -1.10 ± 0.08D, monocular viewing: Emmetropes = -0.81±0.07; Myopes = -1.29±0.09, P<0.001). In both groups, the initial accommodative lags significantly reduced with sustained near activity (mean reduction in lag after 20 minutes of near work, binocular: Emmetropes = 0.21 ± 0.07 D: Myopes = 0.32 ± 0.08 D; monocular: Emmetropes = 0.19 ± 0.08D: Myopes = 0.28 ± 0.07D; P<0.05). The binocular plane of focus showed consistently greater (i.e. more negative) response compared to the monocular plane of focus and the pattern of change in focus was similar under both viewing conditions. This pattern was also similar to previous studies with adult participants. [20, 22]

<INSERT FIGURE 1 (A and B) HERE>

Plane of focus measures through +2D lenses (add condition) are illustrated using solid lines in Fig. 1 A (emmetropic) and 1B (myopic group). Addition of +2D lenses shifted the plane of focus in a myopic direction (P <0.001) compared to the no add condition under both binocular and monocular viewing states. However, the mean binocular and monocular plane of focus varied in terms of the initial response and the pattern of change over time between the two refractive conditions. In the binocular viewing condition, introduction of +2D lenses resulted in greater "*over-focus*" (term used in this study to describe lead of accommodation and denoted by a positive sign) in emmetropes (0.60 ± 0.09 D, Fig. 1A) compared to myopes (0.24± 0.09 D, Fig.

1B) at the onset of near work. The mean monocular plane of focus with add was close to the position of the target (33cm, dashed line in Figs.1 A and B) in the emmetropic group (small over-focus of 0.05 ± 0.08D, Fig 1A) and exhibited a small amount of accommodative lag in the myopic group (-0.15± 0.10 D; Fig. 1B). The difference in plane of focus between the binocular and monocular viewing conditions was statistically significant in both refractive groups at the onset of near work (Emmetropes = 0.48 ± 0.08D; Myopes= 0.44± 0.10D; $P<0.01$). However, this difference was not significantly different between the two refractive groups ($P>0.05$).

During sustained near fixation with the addition lenses, the binocular measures alone showed a significant ($P<0.01$) reduction in focus after 3 minutes of near work in both refractive groups (Reduction in emmetropes = 0.30±0.09D; Myopes = 0.19 ±0.09D, Fig 1A and B). With continued fixation, there was no significant reduction in binocular focus in either refractive group. The reduction in binocular focus placed the mean plane of focus closer to the accommodative demand (dashed line at 3D) in the myopic group in such a way that the near target was almost exactly conjugate with the retina. The monocular plane of focus measures remained quite stable in both the groups with no significant changes throughout the 20 minute fixation period (Fig.1 A and B: solid line with squares; post-hoc tests: $P<0.05$). The difference between binocular and monocular focus was not found to be statistically significant after 3 minutes of sustained viewing.

The accommodative errors (AE) through +2D lenses were compared with respect to a zero difference (relative to 3D) at all time points in both refractive groups. The binocular AE showed significantly greater over-focus at time point 0 in both refractive groups (Emmetropes, AE = 0.60 ± 0.09D; $P<0.001$; Myopes, AE= 0.24± 0.09 D, $P<0.05$). After 3 minutes of sustained fixation, the AE in myopic group did not differ from a zero error (P>0.6) but emmetropes still showed significantly (P<0.05) greater AE (0.28± 0.09D). The monocular accommodative errors were not observed to be significantly different from zero at all time points in both refractive groups (Emmetropes, P>0.6; Myopes, P>0.1).

Tonic accommodation

Fig.2 illustrates the differences in tonic accommodative responses (measured with the DOG target) before and after the 20 minute near task in the refractive groups during the "no add" and "the add" viewing conditions. Both refractive groups showed a significant (P<0.05) myopic shift in tonic accommodation after near work (Accommodative adaptation; Emmetropes = - 0.41 ± 0.07 D; Myopes= -0.56 ±0.15 D) in the no lens condition; however, the difference between the refractive groups was not significant (P>0.8). In the add condition, the tonic changes after prolonged fixation were not significantly different (P >0.6) from the pre-task measurements in either refractive group (Emmetropes: 0.13± 0.07D; Myopes: 0.07 ± 0.07D). Furthermore, the magnitude of accommodative adaptation with +2D lenses was significantly lower (P<0.05) than the amount of adaptation without +2D lenses in both the refractive groups.

<INSERT FIGURE 2 HERE>

Changes in near phoria without and with +2D lenses during near work in the two refractive groups

The average habitual near phoria of the emmetropic and the myopic groups were observed to be -2.80 ± 0.87Δ and -2.88 ± 0.96 Δ respectively (ranged between ortho and -8Δ in both groups with the negative sign indicating exophoria: P>0.05, Fig 3 and Table 1). Fig.3 compares the changes in the mean phoria when participants performed prolonged near work through their habitual correction. The mean changes in near phoria without near addition lenses were observed to be similar in both refractive groups until 9 minutes of near work. Beyond that time, the emmetropic group showed a drift towards esophoria that was statistically significant at the end of the near activity (Fig. 3, dashed line; difference between 9 and 20 minute time points: 1.01 ± 0.74Δ; $P<0.05$). The myopic group did not show any significant change in near phoria even after 20 minutes of near work through their habitual corrective lenses (Fig. 3, solid line; $P>0.05$).

<INSERT FIGURE 3 HERE>

Fig. 4(A and B) shows the changes in near phoria with +2D lenses over time in the two refractive groups. Introduction of +2D lenses (Fig. 4 A and B, solid lines) significantly increased the mean near exophoria by 5.65 ± 0.85 Δ in the emmetropic group and 6.45 ± 0.55 Δ in the myopic group. Continued fixation resulted in a significant reduction ($P<0.001$) in phoria following 3 minutes of near viewing in both groups (Emmetropes=3.79 ± 0.65 Δ; Myopes= 3.03 ± 0.88 Δ). With extended binocular fixation, the mean exophoria in the myopic group showed a further small reduction that was approaching significance (Fig. 4B: Difference between 3 & 20 min time points: 1.12 ± 0.99Δ; P = 0.059). In both refractive groups, the pattern of reduction in exophoria significantly correlated with the reduction in the binocular plane of focus during sustained viewing through the near add (Pearson $r <0.9$; $P<0.05$).

< INSERT FIGURE 4(A and B) HERE>

The changes in near phorias with +2D lenses were fit using an exponential decay function (dashed line in 4A and B) to compare the magnitude and percentage of completeness of adaptation between the two refractive groups. Magnitude (ΔV) refers to the total reduction in near phoria through +2D lenses upon saturation and was determined from the asymptote of the exponential function. The percentage of completeness (PC) was calculated by dividing the amount of phoria reduced over time through +2D lenses by the initial change in phoria induced by the plus lens. We observed the PC to be significantly lower in the myopic group (61.02 ± 1.57%) compared to emmetropes (76.6± 2.10 %; P<0.001) after 20 minutes of near viewing. The mean magnitude of the change in adaptive vergence (ΔV) was also significantly less in myopic (3.95 ± 0.15 Δ) compared to emmetropic children (4.41 ± 0.08 Δ; P<0.01). However, the time constant of phoria reduction (defined as the time taken to reach 63% of total reduction in exophoria) did not show any significant difference between the two refractive groups (emmetropes =1.69± 0.07 min; myopes=2.12 ± 0.08 min; P>0.2).

Effect of AC/A ratio on the reduction of exophoria

Myopic children showed significantly higher response AC/A (RAC/A) ratios compared to the group with emmetropic children (Emmetropes: 5.61 ± 0.61Δ; Myopes: 7.08 ± 0.9Δ, P <0.05). The stimulus AC/A measures were not significantly different between the groups. Fig. 5 shows the relation between RAC/A ratio, magnitude of phoria change (ΔV) and completeness of adaptation in both refractive groups in the add condition. Both myopes and emmetropes showed significant positive correlations between RAC/A and magnitude of adaptation (Pearson r, Emmetropes = 0.64, P<0.05; Myopes, = 0.87, P<0.01). When ΔV was analyzed as a function of AC/A ratio, both refractive groups showed similar slopes (Bivariate regression analysis, Emmetropes = 0.41; Myopes = 0.32; P>0.5) indicating no interaction between refractive error and AC/A ratio. However, the myopic group showed a significant offset (P<0.0005) compared to emmetropes reflecting the reduced magnitude of adaptation observed in this group.

With regards to completeness of adaptation, Fig 5 allows comparison between the actual magnitude of adaptation through near adds (thick lines with symbols) with a reference level (thin lines and no symbols) showing complete adaptation in either refractive group. In comparison with their respective slopes of complete adaptation, the slope of actual adaptation obtained from emmetropes showed significant difference (P<0.003) as a function of AC/A ratio. Emmetropic children with low AC/A ratios showed near complete adaptation but the degree of completeness reduced with an increase in AC/A ratio (Fig 5). On the contrary, the slope of actual adaptation did not differ (P>0.3) from that of complete adaptation in myopes; however, the actual adaptation was significantly offset (P<0.0001; Fig 5) with respect to the complete adaptation, indicating less complete adaptation throughout the range of AC/A ratios observed in the study.

<INSERT FIGURE 5 HERE>

Discussion

This is the first investigation that measured changes to both accommodation and vergence responses when myopic school aged children performed sustained near activity through +2D addition lenses. The main finding of this study was that children with myopia exhibit reduced vergence adaptation to near addition lenses, both in terms of absolute change (magnitude of adaptation) and in terms of proportional change (completeness towards their habitual phoria) compared to emmetropes.

Influence of AC/A ratio on vergence adaptation to lenses in myopes

Irrespective of the refractive error, we observed that the magnitude of phoria adaptation increases with increasing demand of exophoria imposed by higher AC/A ratios; however, myopic children consistently showed reduced magnitudes compared to emmetropes. On the other hand, AC/A ratio influenced the completeness of adaptation in emmetropic children alone. In emmetropes, adaptation was less complete for individuals with higher AC/A ratios, similar to the results of our adult study. [22] Conversely, in the myopic group, children showed less complete adaptation at all AC/A ratios.

The higher response AC/A ratio observed in myopes (similar to previous studies [41, 42]) might be viewed as a cause for the reduced magnitude of adaptation observed in this group of children. If their AC/A ratios were the sole cause of the difference in adaptation, we would expect the absolute change in phoria to be greater in the myopic group since higher AC/A ratios result in greater amounts of induced exophoria, which would drive greater reflex convergence, and greater magnitudes of vergence adaptation. [22, 29, 59] This was not the case. In fact, the average amplitudes of adaptation were greater in our emmetropic group compared to myopes. In addition, results from this investigation indicate that myopes show deficient completeness of adaptation even at low AC/A ratios and the degree of completeness was independent of AC/A. These results suggest that the decreased adaptation found in the myopes is not solely the product of AC/A ratio, supporting the hypothesis proposed by Rosenfield [44] that the vergence adaptive property itself might be reduced in myopes.

Additionally, vergence adaptation to near addition lenses in myopes could appear incomplete if changes occurred to the AV cross-link because of accommodative adaptation. [60] The accommodative aftereffects through +2D lenses demonstrate a small positive shift indicating further accommodative relaxation; however, this change is extremely small in our sample of myopes (less than 0.1D). Furthermore, the monocular focus measures with +2D lenses was steady over time suggesting that the accommodative convergence cross link was not significantly altered during vergence adaptation.

<u>Differences in vergence adaptation to sustained near work</u>

The pattern of change in phoria following sustained near task differed between the two refractive groups when viewing through habitual corrective lenses. Emmetropic children showed a shift towards esophoria while myopes showed no change in phoria with sustained near fixation. The magnitude of esophoric shift in emmetropes (1.01±0.74Δ), although small, is similar to previous studies. [58, 61] Ehrlich [61] reported an esophoric shift of only 1.62 Δ after sustained near fixation despite using a longer task duration (45 min) and closer fixation distance (20 cm) compared to the current study. This smaller (1.01±0.34Δ) magnitude of adaptation compared to the add condition (4.41 ± 0.08Δ) could be attributed to the variable demand (high/low) on fusional vergence system in either (add/no add) conditions. [28] The lack of adaptive change after sustained binocular viewing through habitual lenses in myopes seems to provide additional evidence towards reduced vergence adaptive ability in this group. However, this reduced adaptation can be considered beneficial since a shift towards esophoria might further reduce the accommodative response (due to reduced output from vergence accommodation due to reflex divergence) in an eye with previously large accommodative lag.

Near add, vergence adaptation and accommodation

The general patterns of changes to accommodation and near phoria in both refractive groups were similar to our adult study [22] , with the emmetropic children exhibiting similar time course of adaptation compared to emmetropic adults. More specifically, the introduction of near adds eliminated the excessive lags of accommodation observed in our myopic group comparable to previous studies with myopic children [43] and myopic adults. [23] At the onset of near work, these lenses resulted in a small degree of binocular over-focus in both refractive groups similar to investigations in adults. [19-22] This over-focus was smaller in the myopes compared to emmetropes, presumably due to the large accommodative lags seen during natural viewing conditions in myopic children. Convergence accommodation, which was calculated from the difference between monocular and binocular focus through near add, was greatest at the reading onset in both the groups. This could be attributed to the lens-induced exophoria triggering an increase in reflex convergence, resulting in an immediate increase in binocular focus through the convergence accommodation crosslink. [22, 31-34] During sustained near fixation, vergence adaptation occurred in both refractive groups; however myopic children showed lower magnitude and completeness of adaptation compared to the emmetropes. Vergence adaptation resulted in reduced binocular over-focus in both refractive groups, which resulted in a plane of focus closer to the fixation target in the myopic group and a small over-focus in the emmetropic group. This position of the binocular focus appears to be a product of the monocular accommodative lags, high AC/A ratio and reduced vergence adaptation (leading to a reduced output of convergence accommodation). Based on the results of our study, it appears that +2D lens additions are beneficial for myopic children with large accommodative lags, provided vergence adaptation occurs to minimize accommodative error (over-focus). These results seem to support the findings of a recent clinical trial [13] that show greater treatment effect (i.e. reduced progression of myopia) in children with larger lags of accommodation. Additionally, based on our study results, we extrapolate that lower magnitude plus additions (such as +1D) might not be as beneficial in reducing myopic progression as +2D lenses, at least in a group of myopic children similar to our study. Though earlier studies [20] with emmetropic adults (and smaller accommodative lags) observed a best match between accommodative demand and response through +1D lenses, this magnitude might not work in our myopic study group as these children experienced large accommodative lags. Furthermore, the presence of vergence adaptation to the near addition lens might result in further reduction in the binocular accommodative response resulting in greater lag of accommodation. This increased lag through the low powered near add might possibly explain why a previous longitudinal study [14] showed better treatment effect with +2D lenses compared to +1.50D lenses.

It appears from the results of this study that differences in vergence adaptation do exist between myopes and emmetropes, at least in response to viewing through near adds for 20 minutes. Possibly this adaptation difference may decline after a longer duration of wear. We did not consider longer study durations considering the age of study participants and their shorter attention span. However, it seems unlikely that the adaptation response becomes complete after longer durations, since the phoria response appears to saturate after 9 minutes of binocular fixation through +2D lenses. The reduced vergence adaptive ability observed in myopic children might be a function of their refractive error or due to the nature of their ocular motor parameters (like accommodative response, AC/A ratio). Previous investigations reported no significant difference in prism adaptation in individuals with early onset myopia, late onset myopia and emmetropia.[37] Comparison of prism adaptation was based on results from adult participants (even for the early onset group) whose refractive condition might have become stabilized and furthermore they did not measure accommodative response or response AC/A ratio to investigate the influence of these parameters on vergence adaptation.

The results of this investigation suggest that reduced vergence adaptation is an important factor in prescribing near adds to young myopes in addition to increased accommodative lags and high AC/A ratios. There are two clinical caveats that result. Based on our study we predict that myopic individuals with near esophoria would respond well to the add since the near add would both reduce the lag of accommodation and act to lessen the esophoria towards orthophoria thereby placing less demand upon reflex convergence. The reduced vergence adaptation would be beneficial in avoiding a return to esophoria. However, such adds may not be well tolerated in myopes with a high exophoria, where the reduced vergence adaptation leads to increased exophoria and hence a greater stress on the vergence system.

Conclusions

The results of this investigation demonstrate that myopic children exhibit reduced vergence adaptive ability such that higher amounts of exophoria will remain for myopes compared to emmetropes following adaptation to the lenses. The reduced magnitude of vergence adaptation in myopic children seems to be a product of both the AC/A ratio and the refractive error; however, the degree of completeness appears to be primarily associated with the type of refractive error. In the accommodation system, near adds seem to reduce the excessive accommodative lag observed in myopic children and the presence of vergence adaptation helps minimize errors of both accommodation and vergence systems during sustained near fixation.

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Figure Legends

Fig.1 A and B: Mean plane of focus measures with (solid lines) and without +2D lenses (dotted lines) at 33cm (STA= 3D, dashed line in Fig) in the emmetropic (Fig 1A) and myopic groups (Fig 1B) respectively. Under both conditions, filled triangles represent binocular responses and filled squares represent monocular responses. Error bars indicate mean ± SE

Fig.2. Mean tonic accommodative change (Pre task – post task) in myopic and emmetropic children with and without near addition lenses after 20 minutes of near work. Error bars indicate mean ± SE

Fig.3. Mean phoria responses in both refractive groups in the no lens condition during 20 minutes of near fixation. Error bars indicate mean ± SE

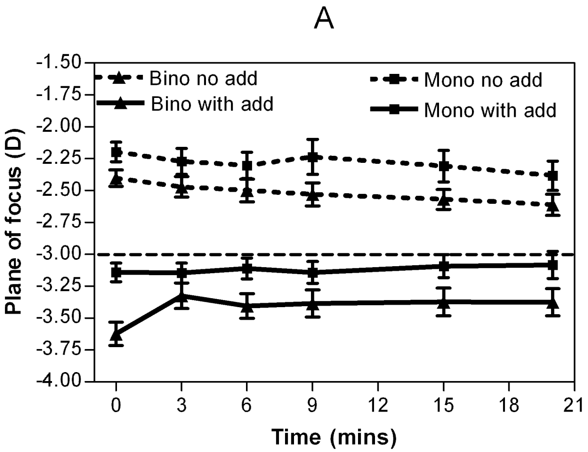
Fig 4 (A and B): Mean phoria responses with (solid line) and without (dotted line) +2D lenses in emmetropic (Fig 4A) and myopic group (Fig 4B). Exponential decay function for the add condition is shown as dashed line in Fig 4A (emmetropic) and 4B (myopic). Error bars indicate mean ± SE

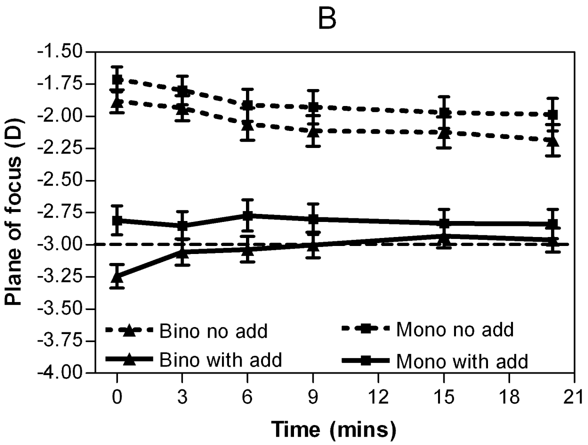
Fig 5: Plot showing the relation between RAC/A ratio, magnitude of phoria change and degree of completeness of adaptation in both refractive groups in the add condition. Responses from emmetropes are shown as open squares and dashed lines while myopes are represented through solid lines and filled circles. In both refractive groups, thick lines indicate actual state of adaptation and thin lines denote complete adaptation (magnitude equivalent to the return of adapted phoria towards habitual level).

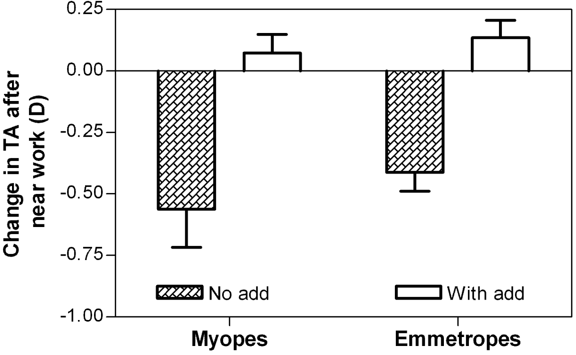
TABLE 1 : Critical visual parameters of myopic and emmetropic children

PARAMETER (MEAN ± SEM; AND RANGE WHERE APPLICABLE)	**EMMETROPES**	**MYOPES**
No of participants	13	11
Age	11 ± 0.65 yrs (7-14)	11 ± 0.58 yrs (7 -14)
Refractive error	0.6 ± 0.12D (0.5 to 1D)	-2.04 ± 0.48D (-0.75 to -3.75D)
Near phoria	-2.80 ± 0.87 Δ (-0.5 to -8 Δ)	-2.88 ± 0.96 (Ortho to -8 Δ)
Distance phoria	-0.45 ± 0.40 Δ (0.5 to -1 Δ)	-0.44 ± 0.43 Δ (0 to -2 Δ)

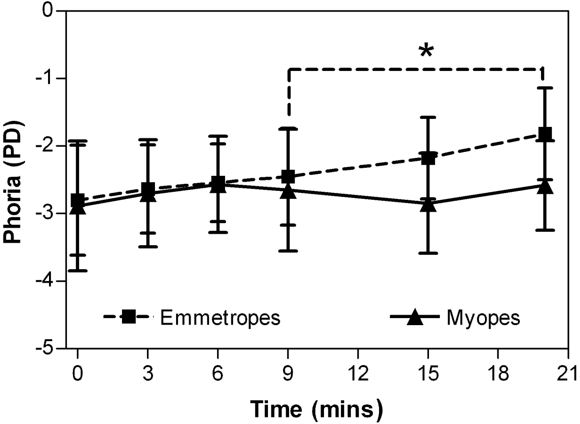
Phoria measures: Negative sign denotes exophoria


A
Bino no add
Bino with add
Mono no add
Mono with add
-1.50
-1.75
-2.00
-2.25
-2.50
-2.75
-3.00
-3.25
-3.50
-3.75
-4.00
Plane of focus (D)
0
3
6
9
12
15
18
21
Time (mins)

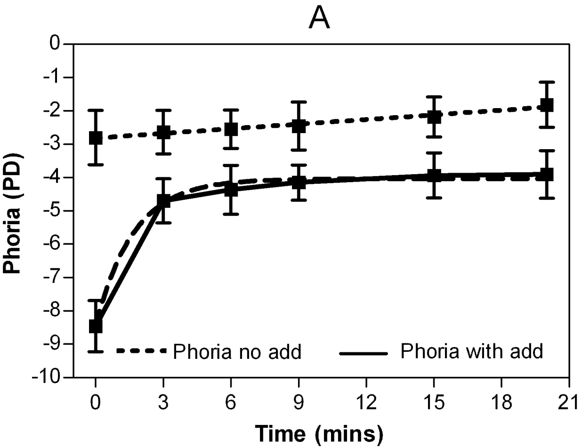

B
Plane of focus (D)
Time (mins)
-1.50
-1.75
-2.00
-2.25
-2.50
-2.75
-3.00
-3.25
-3.50
-3.75
-4.00
0
3
6
9
12
15
18
21
Bino no add
Mono no add
Bino with add
Mono with add

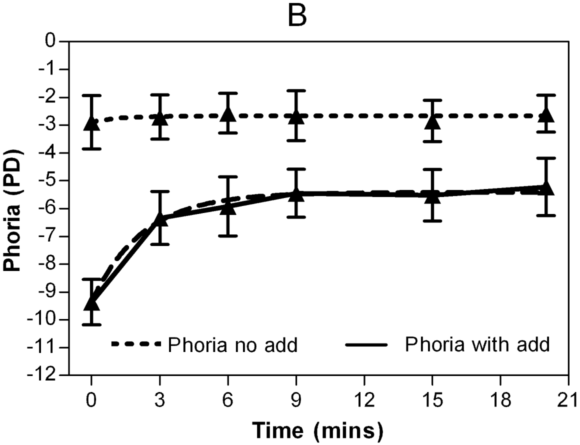


Change in TA after near work (D)
0.25
0.00
-0.25
-0.50
-0.75
-1.00
No add
With add
Myopes
Emmetropes

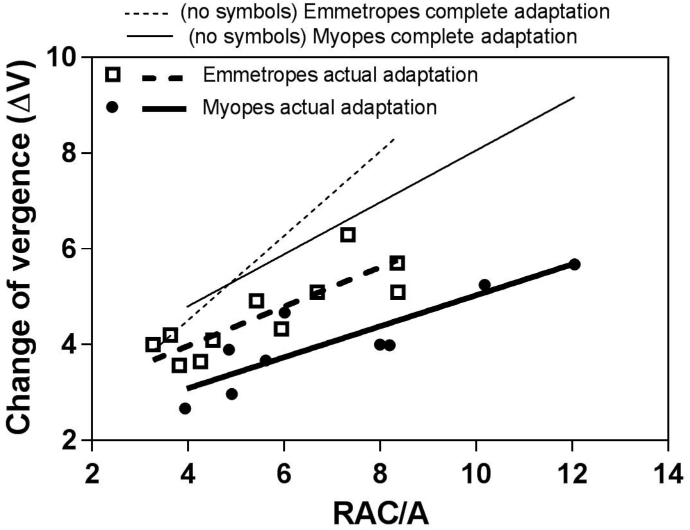


0
-1
-2
-3
-4
-5
Phoria (PD)
*
Emmetropes
Myopes
0
3
6
9
12
15
18
21
Time (mins)


A
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
Phoria (PD)
0
3
6
9
12
15
18
21
Time (mins)
Phoria no add
Phoria with add



B
Phoria (PD)
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
0
3
6
9
12
15
18
21
Time (mins)
Phoria no add
Phoria with add



(no symbols) Emmetropes complete adaptation
(no symbols) Myopes complete adaptation
Emmetropes actual adaptation
Myopes actual adaptation
Change of vergence (ΔV)
RAC/A
10
8
6
4
2
2
4
6
8
10
12
14