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Effect of heterophoria type and myopia on accommodative and vergence responses during sustained near activity in children

Vidhyapriya Sreenivasan *, Elizabeth L. Irving, William R. Bobier

School of Optometry, University of Waterloo, Ontario, Canada

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ABSTRACT

The influence of phoria-type and myopia on changes to vergence and accommodation during prolonged near-task was examined in 53 children. Participants were classified into phoria and refractive categories based on near phoria and cycloplegic refraction respectively. Measures of near phoria, binocular (BA) and monocular accommodation (MA) were obtained before and during a 20 min task when children binocularly fixated a high-contrast target at 33 cm through best corrective lenses. Vergence adaptation and accommodative adaptation were quantified using changes to near phoria and tonic accommodation respectively. The direction and magnitude of vergence adaptation was modified by the phoria-type ($p < 0.001$). Emmetropic exophores displayed convergent (less exo than baseline) adaptation while esophores showed divergent shifts (less eso than baseline) in phoria upon prolonged fixation. Myopic children also followed a similar pattern but showed greater divergent (or less convergent) shift ($p < 0.001$) in vergence adaptation for all phoria categories compared to emmetropes. Phoria-type also influenced the pattern of BA vs. MA ($p < 0.001$) such that exophores showed BA > MA while esophores showed MA > BA in both refractive groups. Accommodative adaptation was higher in myopes ($p = 0.010$) but did not demonstrate a significant effect of phoria ($p = 0.4$). The influence of phoria-type on vergence adaptation and the pattern of BA vs. MA relates primarily to the varying fusional vergence demands created by the direction of phoria. The greater divergent (or less convergent) shift in vergence adaptation seen in myopes (compared to emmetropes) could be attributed to their higher accommodative adaptation. Nevertheless, the adaptive patterns observed in myopic children do not appear to explain their high response AV/A ratios identified as a risk factor for myopia development.

1. Introduction

1.1. Near work and the accommodation, vergence response

Near work requires the activation of the accommodation and vergence systems to achieve clear and single binocular vision. Numerous studies have shown that sustained near fixation induces adaptation of the accommodation and vergence systems (Ebenholtz, 1983; Ehrlich, 1987; Fisher, Ciuffreda, & Levine, 1987; Gilmartin & Bullimore, 1991; Owens & Wolf-Kelly, 1987; Schor, Johnson, & Post, 1984; Wolf, Ciuffreda, & Jacobs, 1987; see Rosenfield (1997), Rosenfield, Chiu, et al. (1994) and Rosenfield, Ciuffreda, et al. (1994) for review). This adaptation has been attributed to the prolonged rate of decay of the slow controller of vergence/accommodation, which replaces the fast controller and exhibits a shift in the tonic levels of accommodation/vergence (Schor, 1979a, 1979b). Accommodative adaptation is characterized by a post-task shift in the dark focus or tonic accommodation (Bullimore & Gilmartin, 1989; Ebenholtz, 1983; Fisher, Ciuffreda, & Levine, 1987; Gilmartin & Bullimore, 1991; McBrien & Millodot, 1988). In the vergence system, past studies show convergent (eso) shifts in tonic vergence after a period of sustained near work (Ehrlich, 1987; Owens & Wolf-Kelly, 1987; Wolf, Ciuffreda, & Jacobs, 1987).

1.2. Phoria and near task adaptation

Heterophoria (phoria) is a misalignment of the visual axes that occurs in the absence of fusion. This deviation is compensated during binocular viewing by fusional vergence. The degree and type of fusional vergence required for binocular viewing (convergence/divergence) varies directly with the size and direction of the phoria (exo/eso). The presence of exophoria necessitates an increase in fast fusional convergence while an esophoric deviation requires an increase in reflex fusional divergence to attain binocular single vision. Prolonged output of the fast fusional vergence (convergence/divergence) leads to vergence adaptation, which results in phoria changes in the direction of the elicited fusional vergence

* Corresponding author. Address: School of Optometry, 200, University Avenue West, Waterloo, Ontario, Canada N2L 3G1.
E-mail address: vsreeniv@sciborg.uwaterloo.ca (V. Sreenivasan).

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(Schor, 1979a) Thus, differing vergence postures (esophoria/exophoria) may produce asymmetries in phoria adaptation to a near-task (Ehrlich, 1987; Owens & Wolf-Kelly, 1987). Ehrlich (1987) measured changes to near phoria before and after a 2 h near task at 20 cm in adult participants with mixed refractive errors. A mean convergent shift of 1.62 Δ and a significant relationship between pre-task near phoria and vergence adaptation was reported. However, the sample only consisted of one esophore (others ranged from ortho to 16 exo). Also, only individuals with exophoria greater than 5 Δ demonstrated a convergent shift similar to the mean (Fig. 3 of the paper). Participants with low exo/ortho showed a divergent shift in phoria, which was not readily explained by their fusional demand. The author did not measure accommodative adaptation (changes to dark focus) but reported 0.29 D change in distant refraction (transient myopia in closed loop accommodation) after the near task. Differences in accommodative adaptation, combined with varying strengths of accommodative-vergence cross-link may explain the divergent shift in vergence adaptation (Schor & Kotulak, 1986) seen in low exo/orthophores.

Most of the above-cited works on near task adaptation were performed in adults; relatively limited studies have measured adaptation in children (Gwiazda et al., 1995; Rosenfield, Chiu, et al., 1994; Rosenfield, Ciuffreda, et al., 1994; Wong, Rosenfield, & Wong, 2001; Woung et al., 1993). Wong, Rosenfield, and Wong (2001) compared vergence adaptation in children (mean age = 9.8 - years) and young adults (mean age = 25.8 years) by measuring tonic vergence before and after a prolonged near task (reading at a distance of 15 cm for 5 min under closed loop accommodation and vergence). Children showed significantly greater vergence adaptation (0.45 MA) compared to adults (0.11 MA). However, other ocular motor parameters like accommodative adaptation and AV/A ratio that may alter the vergence response and hence, its adaptation were not reported. Given that accommodation and vergence are tightly coupled systems, it is crucial to measure changes to both systems, especially when the adapting stimulus involves dual closed-loop conditions. To date, no study has measured adaptation of both accommodation and vergence in response to a sustained near task in children, and there is a paucity of information on the role of childhood phoria levels on this adaptation.

1.3. Myopia and adaptation to sustained near task in children

Numerous studies have identified refractive group differences in near work attributes. Myopic children show a reduced accommodative response especially under monocular viewing conditions (Berntsen et al., 2011; Gwiazda et al., 1993; Mutti et al., 2006) and full correction (Nakatsuka et al., 2005), increased variability of accommodation (Langaas et al., 2008; Sreenivasan, Irving, & Bobier, 2011), elevated response AV/A ratios (Gwiazda, Grice, & Thorn, 1999; Mutti et al., 2000), and recently, reduced fusional vergence ranges (Anderson et al., 2011). With regards to near-task induced adaptation, Gwiazda et al. (1995) showed that myopic children exhibit greater accommodative adaptation to a near task compared to emmetropes. Since myopes demonstrate elevated response AV/A ratios (Gwiazda, Grice, & Thorn, 1999; Mutti et al., 2000), even small differences in the accommodative system may produce larger changes in their vergence system compared to emmetropes.

Esophoria is associated with the onset or progression of myopia (Goss, 1990; Goss & Wolter, 1999) and with higher amounts of myopia (Chung & Chong, 2000). Goss and Rosenfield (1998) speculated that increased vergence adaptation to a prolonged near task may be a source for this convergent shift and thus a possible risk factor for myopic development/progression. However, to date, no study has measured vergence adaptation to a near task in myopic children with varying near phoria profiles. It may be possible that myopic children with different near phorias exhibit varying directions and magnitudes of phoria adaptation due to the alterations in fusional vergence demand. Further, if myopes show larger accommodative adaptation (Gwiazda et al., 1995; Woung et al., 1993), they may show reduced vergence adaptation, based on the reciprocal relation between the adaptive parameters observed in earlier reports (Schor, 1988a, 1988b). Such adaptive behaviour may enhance the accommodative response and reduce the blur produced by excessive accommodative lags under binocular viewing conditions. To investigate the above mentioned hypothesis, this study evaluated the influence of phoria category (eso/exo/phoria normals) and myopia on near-task adaptation of vergence and accommodation following sustained binocular fixation at 33 cm through best corrective lenses.

2. Methods

2.1. Study participants

Fifty-three children (28 myopic and 25 emmetropic; 58% female) between the ages of 7 and 15 years were recruited from the clinic database at the School of Optometry, University of Waterloo. Informed consent (parents) and assent (children) were obtained after verbal and written explanation of the nature of the study. The protocol followed the tenets of Declaration of Helsinki and received approval from the University of Waterloo ethics review board.

Participants with normal general and ocular health (determined from their clinical records and confirmed during a screening visit) underwent a preliminary examination to ensure the following: myopia between −0.75 and −6 D or "*emmetropia*" between +0.25 and +1.5 D, determined using cycloplegic refraction (two drops of 1% tropicamide added to both the eyes followed by retinoscopy and subjective refraction 20 min after the 2nd cycloplegic drop); astigmatism < 1 D; anisometropia < 1 D; best corrected visual acuity of at least 6/6 in each eye; non-strabismic; normal amplitudes of accommodation. Further, it was confirmed that participants were not taking any medications that might influence the accommodation and vergence systems. The range of refractive error in the "emmetropic group" was set to ensure that participants were clearly not myopic and therefore confirm distinct refractive differences between the study groups.

All children were classified into one of the three phoria categories based on their near phoria at 33 cm. Participants were classified as "*phoria normals*" if their near phorias were between 0 and 4 exo, *exophores* if phorias were >6 exo or *esophores* if phorias were >2 eso. Table 1 lists the critical visual parameters, including the number of children in each refractive and phoria category.

2.2. Instrumentation

The overall study design involved prolonged binocular viewing through distance corrective lenses for 20 min with periodic measurements of phoria and accommodation, to quantify the time course of changes in either system. The instrumentation and procedure used for accommodation and phoria measurements were similar to previous studies (Sreenivasan, Irving, & Bobier, 2008, 2009).

2.2.1. Measurement of vergence adaptation and accommodation

Vergence adaptation was quantified by measuring changes in near phoria using the modified Thorington technique (MTT). This technique has been shown to be repeatable and valid in adults and in children (Casillas & Rosenfield, 2006; Rainey et al., 1998; Schroeder et al., 1996; Sreenivasan, Irving, & Bobier, 2008). Near phoria was measured at 33 cm using the modified Thorington