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Can current models of accommodation and vergence predict accommodative behavior in myopic children?

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ABSTRACT

Investigations into the progression of myopia in children have long considered the role of accommodation as a cause and solution. Myopic children show high levels of accommodative adaptation, coupled with accommodative lag and high response AC/A (accommodative convergence per diopter of accommodation). This pattern differs from that predicted by current models of interaction between accommodation and vergence, where weakened reflex responses and a high AC/A would be associated with a low not high levels of accommodative adaptation. However, studies of young myopes were limited to only part of the accommodative vergence synkinesis and the reciprocal components of vergence adaptation and convergence accommodation were not studied in tandem. Accordingly, we test the hypothesis that the accommodative behavior of myopic children is not predicted by current models and whether that departure is explained by differences in the accommodative plant of the myopic child. Responses to incongruent stimuli (−2D, +2D adds, 10 prism diopter base-out prism) were investigated in 28 myopic and 25 non-myopic children aged 7–15 years. Subjects were divided into phoria groups – exo, ortho and eso based upon their near phoria. The school aged myopes showed high levels of accommodative adaptation but with reduced accommodation and high AC/A. This pattern is not explained by current adult models and could reflect a sluggish gain of the accommodative plant (ciliary muscle and lens), changes in near triad innervation or both. Further, vergence adaptation showed a predictable reciprocal relationship with the high accommodative adaptation, suggesting that departures from adult models were limited to accommodation not vergence behavior.

1. Introduction

1.1. Myopia and accommodation

Myopia has reached epidemic levels in certain groups in a number of Asian countries. Morgan, Ohno-Matsui, and Saw (2012) points out that 80–90% of school completers in the urban areas of many Asian countries such as Hong Kong, China and Japan are myopic. Myopia is often defined by its time of onset; congenital accounting for about 5% (Banks, 1979); early onset myopia appearing in the school aged years and late onset found typically in older teenagers often in university or college (Baldwin, 1990). Human investigations show that myopia also results from excessive axial length of the eye with the vitreal chamber accounting for most of the growth (Larsen, 1971). Accommodation has been viewed as a possible source of progressing myopia for well over a century (see review – Sivak, 2012). Early thinking was based upon the idea that the prolonged accommodation resulting from near work acted to increase the axial length of the eye. This led to preventive strategies such as bifocals, eye exercises, and pharmacological investigations, as an attempt to alleviate myopic progression by reducing accommodative activity. Research investigations failed to find a clinically significant effect of bifocals on myopia progression (reviewed in Walline et al., 2011; Sivak, 2012). Controlling accommodation with bifocals re-appeared following extensive study of the role of hyperopic defocus as a key factor in myopia development. A multitude of animal species have shown that hyperopic retinal defocus may trigger axial elongation resulting in myopia, provided they were studied in their early days or weeks of life, or the eye defocused in a direction which required increased axial growth in order that the retina was conjugate with the point of regard (Irving, Callender, & Sivak, 1991; Schaeffel, Glasser, & Howland, 1988; Troilo & Wallman, 1991; Smith & Hung, 1999; Wallman & Winawer, 2004). Accommodative lag has been

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considered a possible source of hyperopic defocus. Myopic children show reduced steady state accommodative response under monocular viewing conditions (Berntsen et al., 2011; Mutti et al., 2006) or when viewing thorough full correction (Berntsen et al., 2011; Nakatsuka et al., 2005) or when accommodation was stimulated using minus lenses (Gwiazda et al., 1993, 1995a). Further, myopic children also show an increased variability of accommodation compared to emmetropes (Langaas et al., 2008; Sreenivasan, Irving, & Bobier, 2011). A few studies have suggested sensory differences such as higher blur detection thresholds and higher depth of focus (Jiang & Morse, 1999; Rosenfield & Abraham-Cohen, 1999; Vasudevan, Ciuffreda, & Wang, 2006) to explain the larger accommodative error observed in myopes. This then pointed to the application of bifocal or progressive lenses – now as a means to reduce hyperopic defocus rather than prolonged accommodation. Results from carefully controlled trials find only very small albeit significant changes in myopia progression (reviewed in Walline et al., 2011; Sivak, 2012). However, several studies point to greater success when the bifocal was worn by a child having reduced accommodation and/or high esophoria (Goss & Grosvenor, 1990; Fulk, Cyert, & Parker, 2002; Gwiazda, 2011).

The accommodation and vergence ocular motor systems provide focused and aligned retinal images that facilitate normal functioning of the visual system. In children, as in primates in general, accommodation and vergence are tightly linked through the neural cross-links accommodative vergence (AC/A i.e. accommodative convergence per diopter of accommodation) (Alpern & Ellen, 1956a, 1956b) and vergence accommodation (CA/C i.e. convergence accommodation per diopter of convergence) (Fincham & Walton, 1957). Further, both accommodation and vergence undergo adaptation when viewing is prolonged (Hung & Ciuffreda, 1991, 1999; Maxwell, Tong, & Schor, 2012; Schor, 1986; Schor, Kotulak, & Tsuetaki, 1986; Hung (1992); Rosenfield and Gilmartin (1999); Semmlow & Yuan, 2002). This behavior is summarized in Fig. 1.

If the accommodative behavior of myopic children is to be fully understood, then the interaction of accommodation with other parameters within the accommodative vergence synkinesis needs to be examined. A number of associated parameters such as accommodative adaptation and AC/A have been examined in addition to accommodative lag. Studies that looked at accommodative adaptation or its manifestation as near induced transient myopia (Ciuffreda & Wallis, 1997) have consistently reported that myopic children have high levels of accommodative adaptation (Ciuffreda & Wallis, 1997; Gwiazda et al., 1995b; Strang, Winn, & Gilmartin, 1994; Woung et al., 1993). Clinical investigations which looked at phorias, among other standard optometric tests found a strong relationship between high esophoria at near testing distances and the development and progression of myopia (Goss, 1990; Goss & Jackson, 1996; Goss & Zhai, 1994). This then strongly suggests that the AC/A would be high as well (Scheiman & Wick, 2002). Direct measures of the AC/A, measured using the gradient or calculated method (Gwiazda, Grice, & Thorn, 1999; Gwiazda, Thorn, & Held, 2005) or by changing accommodation in a Badal set up (Mutti et al., 2000a) show elevated ratios in young myopes. There is disagreement whether the ratio is high prior to myopia onset (Gwiazda, Thorn, & Held, 2005) or whether it occurs only after myopia onset (Mutti et al., 2000a). Also the origin of the high AC/A has been debated. Mutti and associates (Mutti et al., 2000a) hypothesized that the most likely explanation would be a difference in the accommodative plant (i.e. ciliary muscle and crystalline lens) between myopes and non-myopes. They postulated that accommodation could become attenuated if the crystalline lens in myopes where to exert greater force on the choroid, thereby attenuating its transduction effect in accommodation. The evidence is not direct but comes from inferences taken from their data that shows different patterns of changes in crystalline lens development in myopes and non-myopes (Zadnik et al., 1995). Recently, myopes have been found to show a thickened ciliary muscle (Buckhurst et al., 2013; Lewis et al., 2012; Lossing et al., 2012). Specifically, the posterior fibers are thickened in myopia while apical fibers are thicker in hyperopia (Pucker et al., 2013). However evidence indicating whether accommodation is attenuated proportionally due to plant differences has not been found (Schultz et al., 2009).

In summary, the accommodative behavior of young myopes shows high accommodative adaptation coupled with reduced reflexive properties and a high AC/A. Examination of Fig. 1 shows some inconsistencies. The findings of a high AC/A, reduced accommodative responses coupled with a high degree of accommodative adaptation does not fit the expected innervational patterns predicted by these models where high accommodative adaptation would result in reduced AC/A. Also it is unclear how a high level of accommodative adaptation could result from reduced reflexive accommodation. However, the findings have been taken from studies where often only one parameter was examined (e.g.) reflex accommodation. Furthermore, there was no data on vergence adaptation and CA/C measures to put the accommodative measures in context.

1.2. Our previous investigations using near adds in myopic children

Our lab developed a research design where we began a detailed investigation of the accommodative vergence synkinesis in adults

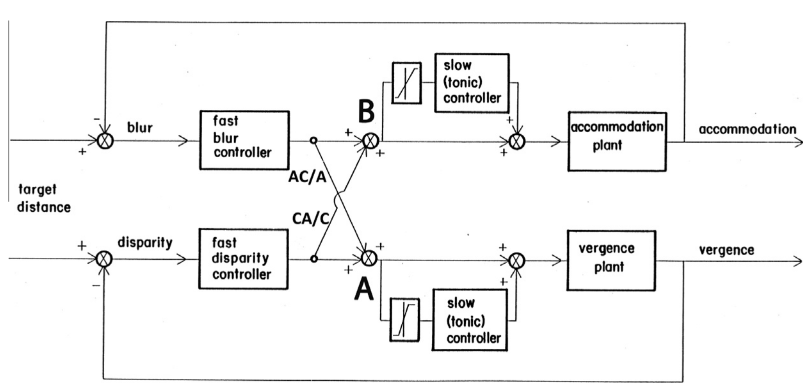

Fig. 1. Accommodation and vergence are represented as two negative feedback systems which act to keep vision clear and single by responding to any perturbations in blur or disparity. Two reciprocal cross-links, AC/A and CA/C provide accommodative driven convergence and vergence driven accommodation respectively. Changes in either blur or disparity are responded by reflex or phasic elements of accommodation or vergence respectively. Once viewing is prolonged, reflex innervations is replaced by tonic, which also serve to attenuate either the AC/A or CA/C. Plant elements of accommodation (lens and ciliary muscle) and vergence (E.O.Ms) affect the motor change. The output is fed back and compared with the stimulus level. (A) Represents a summing junction where innervations from the AC/A and disparity vergence sum together (see text) while (B) defines the same for CA/C and accommodation. Adapted from Bobier and McRae (1996).