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Are high lags of accommodation in myopic children due to motor deficits?

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Children with a progressing myopia exhibit an abnormal pattern of high accommodative lags coupled with high accommodative convergence (AC/A) and high accommodative adaptation. This is not predicted by the current models of accommodation and vergence. Reduced accommodative plant gain and reduced sensitivity to blur have been suggested as potential causes for this abnormal behavior. These etiologies were tested by altering parameters (sensory, controller and plant gains) in the Simulink model of accommodation. Predictions were then compared to the static and dynamic blur accommodation (BA) measures taken using a Badal optical system on 12 children (6 emmetropes and 6 myopes, 8–13 years) and 6 adults (20–35 years). Other critical parameters such as CA/C, AC/A, and accommodative adaptation were also measured. Usable BA responses were classified as either typical or atypical. Typical accommodation data confirmed the abnormal pattern of myopia along with an unchanged CA/C. Main sequence relationship remained invariant between myopic and nonmyopic children. An overall reduction was noted in the response dynamics such as peak velocity and acceleration with age. Neither a reduced plant gain nor reduced blur sensitivity could predict the abnormal accommodative behavior. A model adjustment reflecting a reduced accommodative sensory gain (ASG) coupled with an increased AC cross-link gain and reduced vergence adaptive gain does predict the empirical findings. Empirical measures also showed a greater frequency of errors in accommodative response generation (atypical responses) in both myopic and control children compared to adults.

1. Introduction

Progressive myopes exhibit an accommodative behavior characterized by high response lags that increase with the demand (Gwiazda, Bauer, Thorn, & Held, 1995a; Gwiazda, Thorn, Bauer, & Held, 1993; Koomson, Amedo, Ampeh, Bonsu, & Opoku-baah, 2015; Mutti et al., 2006; Nakatsuka, Hasebe, Nonaka, & Ohtsuki, 2005), elevated response AC/A (Gwiazda, Grice, & Thorn, 1999; Gwiazda, Thorn, & Held, 2005; Mutti, Jones, Moeschberger, & Zadnik, 2000), and high accommodative adaptation (Gwiazda, Bauer, Thorn, & Held, 1995b; Sreenivasan, Irving, & Bobier, 2012). These patterns are not predicted by the currently accepted models of accommodation and vergence which suggest that a high accommodative adaptation would be associated with a low AC/A and smaller response lags (Schor, 1992; Schor & Bharadwaj, 2006). Myopes also show high steady state fluctuations (Langaas et al., 2008; Sreenivasan, Irving, & Bobier, 2011), reduced vergence adaptation (Sreenivasan et al., 2012) and a large depth of focus (Rosenfield & Abraham-Cohen, 1999; Vasudevan, Ciuffreda, & Wang, 2006). Furthermore, several studies showed that the onset of myopia is associated with changes in the accommodative response (Gwiazda et al., 2005; Mutti et al., 2006). Interestingly, this abnormal behavior is associated only with progressive and not stable myopia (Abott, Schmid, & Strang, 1998; Gwiazda et al., 1995a; Jiang & Morse, 1999). Nevertheless, these patterns of accommodation do not appear to be causative because correction of the lags does not reduce the myopic progression to a significant clinical level (Berntsen, Sinnott, Mutti, & Zadnik, 2012; Gwiazda et al., 2004; Shapiro, Kelly, & Howland, 2005).

Studies on children and adults have found differences in the accommodative plant of myopes, specifically, altered crystalline lens growth (Goss, Van Veen, Rainey, & Feng, 1997; Jones et al., 2005; Mutti et al., 1998, 2000, 2012; Shih, Chiang, & Lin, 2009; Zadnik, Mutti, Fusaro, & Adams, 1995) along with a thick and rigid ciliary muscle (Bailey, Sinnott, & Mutti, 2008; Buckhurst, Gilmartin, Cubbidge, Nagra, & Logan, 2013; Jeon, Lee, Lee, & Moon, 2012; Lewis, Kao, Sinnott, & Bailey, 2012; Lossing, Sinnott, Kao, Richdale, & Bailey, 2012; Oliveira, Tello, Liebmann, & Ritch, 2005;

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Pucker, Sinnott, Kao, & Bailey, 2013). Previous work showed that the equatorial growth of the crystalline lens ceases earlier in myopes compared to the non-myopes (Mutti et al., 1998). They predicted that the failure of the lens to compensate for the axial growth of the eye could lead to an increased tension on the choroid and hinder accommodation. However, no study to date has shown if these anatomical differences would actually lead to an abnormal accommodative behavior. A recent investigation (Gwiazda, Norton, Hou, Hyman, & Manny, 2015) found no correlation between myopia progression and changes in the lens growth pattern. They concluded that changes in the lens thickness do not accompany or cause myopia and could be merely coincidental.

Reduced blur sensitivity was found in both young and adult myopes (Gwiazda et al., 1993, 1995a; Jiang, 1997; Schmid, Robert Iskander, Li, Edwards, & Lew, 2002). This reduction was speculated to increase the depth of focus (DOF) thereby leading to a reduced accommodative response. In agreement, studies found a large depth of focus in myopes both objectively (Vasudevan et al., 2006) and subjectively (Rosenfield & Abraham-Cohen, 1999). Increased higher order aberrations were also suggested to increase the depth of focus in myopes by degrading the retinal image quality, ultimately leading to an inaccurate accommodation (Charman, 2005; He, Gwiazda, Thorn, Held, & Vera-Diaz, 2005). Furthermore, studies looking at genetic mutations in myopes found an altered behavior in the retinal processing (Morgan, Rose, & Ashby, 2014). We speculate that these mutations could influence blur processing, possibly a decreased blur sensitivity which occurs at the level of retina. Previously, accommodative sensory gain (ASG) parameter was introduced into a static model of accommodation along with the dead space operator (DOF) to account for the sensory (blur) component (Jiang, 1997). Unlike DOF, the ASG predicted increased response lags as the stimulus demand increased, similar to the empirical accommodative measures.

1.1. Model simulations

In summary, empirical studies suggest that the abnormal pattern of accommodation could either reflect a motor deficit (e.g. a rigid lens and/ or a sluggish ciliary muscle), or sensory deficit (i.e. reduced blur sensitivity) or perhaps a combination of both. A Simulink model (MATLAB) was devised, as shown in Fig. 1, by including the ASG component into the current model of accommodation proposed by Schor and his associates (Maxwell, Tong, & Schor, 2010; Schor, 1992; Schor & Bharadwaj, 2006). Simulations were carried out to determine if these deficits would predict the abnormal accommodative behavior. Table 1 lists the outcomes of the model adjustments.

As shown in Table 1, only simulation with a reduced accommodative plant gain predicted the abnormal behavior found in myopes. A rigid plant would also predict an altered main sequence (reduced rate of change of velocity and acceleration over response amplitude) coupled with a reduced accommodative response to both blur and disparity. To date there has been no measure of main sequence characteristics of the blur-driven accommodative responses in myopic children. While our group previously found no attenuation of convergence accommodation (CA) in children, they do point out that CA output might have been prolonged due to the decreased vergence adaptation found in the myopic children

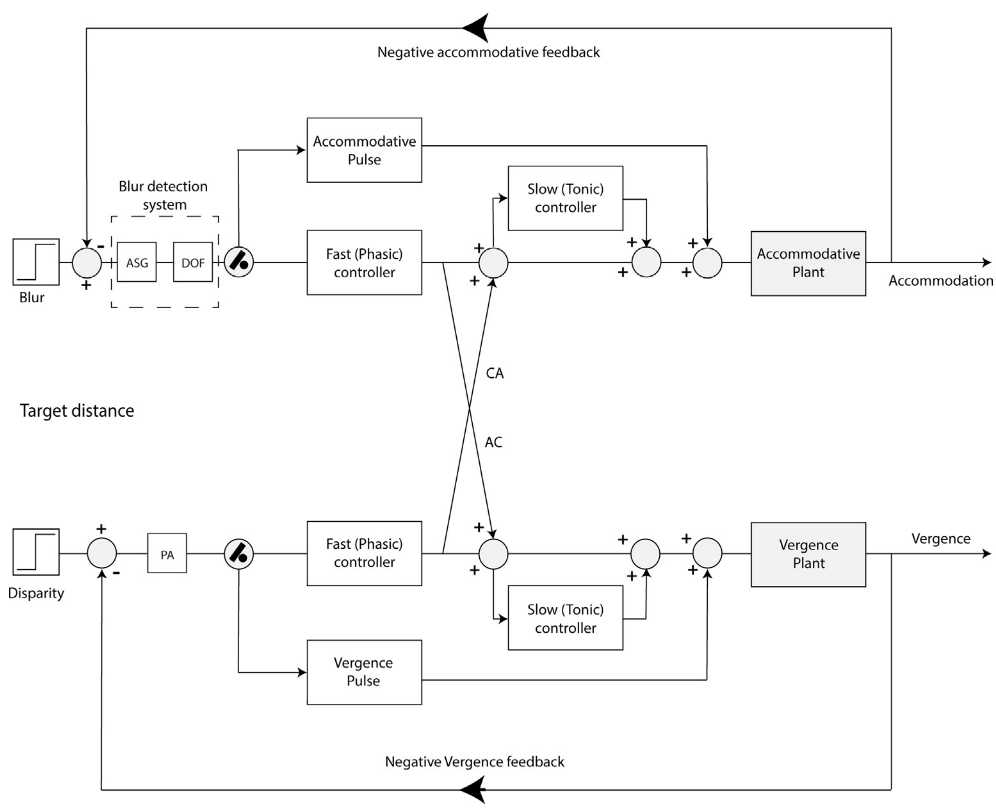

Fig. 1. Model of accommodation and vergence adapted for myopes (Adapted from Jiang, 1997; Maxwell, Tong, & Schor, 2010; Schor, 1992). The control mechanism of accommodation and vergence is characterized by a pulse step innervation. For accommodation, response to a step stimulus is initiated by an open-loop pulse followed by a closed loop step system that code for the dynamic characteristics and position respectively. The closed loop step system is predicted to be under the influence of an internal feedback to avoid errors in the response. The interactions between accommodation and vergence are characterized by pulse and step cross-link. For simplicity, we have not shown the internal feedback and the pulse cross-link mechanism. The cross-links CA and AC are approximated empirically using measures of CA/C and AC/A respectively and are represented as gains in the model. We also adapted the ASG (Jiang, 1997) into this model to address the blur detection system of accommodation. DOF: Depth of focus; PA: Panum's area and ASG: Accommodative sensory gain.