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Tonic accommodation predicts closed-loop accommodation responses

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ABSTRACT

The purpose of this study is to examine the potential relationship between tonic accommodation (TA), near work induced TA-adaptation and the steady state closed-loop accommodation response (AR). Forty-two graduate students participated in the study. Various aspects of their accommodation system were objectively measured using an open-field infrared auto-refractor (Grand Seiko WAM-5500). Tonic accommodation was assessed in a completely dark environment. The association between TA and closed-loop AR was assessed using linear regression correlations and *t*-test comparisons. Initial mean baseline TA was 1.84 diopter (D) (SD ± 1.29 D) with a wide distribution range (−0.43 D to 5.14 D). For monocular visual tasks, baseline TA was significantly correlated with the closed-loop AR. The slope of the best fit line indicated that closed-loop AR varied by approximately 0.3 D for every 1 D change in TA. This ratio was consistent across a variety of viewing distances and different near work tasks, including both static targets and continuous reading. Binocular reading conditions weakened the correlation between baseline TA and AR, although results remained statistically significant. The 10 min near reading task with a 3 D demand did not reveal significant near work induced TA-adaptation for either monocular or binocular conditions. Consistently, the TA-adaptation did not show any correlation with AR during reading. This study found a strong association between open-loop TA and closed-loop AR across a variety of viewing distances and different near work tasks. Difference between the correlations under monocular and binocular reading condition suggests a potential role for vergence compensation during binocular closed-loop AR.

1. Introduction

Under natural viewing conditions, the accommodative system of the human eye mainly employs a retinal blur signal to drive an accurate accommodative response (AR) using a closed-loop negative feedback system under monocular condition (Toates, 1972). In the absence of an adequate visual stimulus, the feedback loop is opened and accommodation rests at an intermediate myopic posture that typically varies individually between −0.5 diopter (D) and 4.5 D (Gilmartin, Hogan, & Thompson, 1984; Heron, Smith, & Winn, 1981; Leibowitz & Owens, 1975, 1978; Maddock, Millodot, Leat, & Johnson, 1981). This posture has been described as tonic accommodation (TA), (McBrien & Millodot, 1987) but terms such as dark focus (Leibowitz & Owens, 1975) or dark accommodation (Rosenfield, Ciuffreda, & Gilmartin, 1992) also have been used when the AR is measured in complete darkness under open-loop conditions.

TA measurements are influenced by a number of factors, including which instrumentation method are used, task and environmental conditions, and mental state of the observer (see Rosenfield, Ciuffreda, Hung, & Gilmartin, 1993 for an extensive review). To open the accommodation loop and measure TA, one preferred method is to record accommodation posture in the dark with an open-field, infrared auto-refractor during passive viewing. In general, studies that have used the dark focus procedure find mean TA values in the range of 0.74–1.15 D (Andre & Owens, 1999; Bullimore & Gilmartin, 1989; Bullimore, Gilmartin, & Hogan, 1986; Gray, Strang, Winfield, Gilmartin, & Winn, 1998; McBrien & Millodot, 1987; Strang, Gilmartin, Gray, Winfield, & Winn, 2000). However, only a few of these studies reported correcting for distance residual uncorrected refraction error. Based on the combined results from two studies that adjusted for residual refractive error, a young adult sample of 226 students had a mean

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dark TA value of 0.78 D (McBrien & Millodot, 1987; Strang et al., 2000).

Many different factors have been found to influence the accuracy of AR under normal or abnormal binocular conditions, such as task instructions (Winn, Gilmartin, Mortimer, & Edwards, 1991), residual uncorrected refractive error (Hasebe, Nonaka, & Ohtsuki, 2005), higher-order aberrations of the eye (Hazel, Cox, & Strange, 2003), and pupil diameter (via mechanism of depth-of-focus) (Wang & Ciuffreda, 2006). Based on the currently well-accepted dual-interaction model of steady-state accommodation (Hung & Semmlow, 1980), the impact of TA on the steady state AR at near is usually considered to be minimal and the accommodative controller gain (ACG) would be the primary contributor to AR, assuming a normal depth of focus (Hung & Semmlow, 1980; Rosenfield et al., 1993). However, this conclusion was based on very limited empirical evidence (4 subjects' data in Hung's original 1980 paper) and computer simulation thereafter (Hung, 1998).

In contrast to the conventional view that TA makes a minimal contribution to the AR, unpublished data from our research group showed a significant correlation between TA level and clinical accommodative testing such as accommodative facility (Liu, Chase, Drew, & Castellanos, 2013), leading us to re-examine the relationship. Among previous literature, Miller (1980) had revealed the only direct evidence that individuals' AR to target located at various viewing distances was significantly correlated to their dark focus (TA) baseline. Miller examined this correlation under both monocular and binocular viewing conditions for the closed-loop AR. Results indicated that the relationship of AR to TA was stronger for the monocular condition than for the binocular condition. This difference indicates a potential role of the vergence system on AR through the convergence accommodation (CA) pathway. Some limitations exist in this study, such as low sample size (n = 13) and the lack of continuous monitoring of the AR during the task.

Other studies also have examined the relationship between near work-induced TA adaptation and AR accuracy. Schor, Kotulak, and Tsuetaki (1986) found that the amplitude of near work-induced TA adaptation was reciprocally related to the amplitude of accommodative lag. But such an effect only manifested when the TA was assessed by opening the loop with Maxwellian view or Ganzfield, not with darkness. Owens and Wolf-Kelly (1987) also observed that one-hour of reading at 20 cm caused a myopic shift in both TA and monocular closed-loop AR. This increase in TA after reading was associated with less AR error. Rosenfield and Gilmartin (1999) assessed TA adaptation by comparing pre- and post-near task dark accommodation level. The adaptor group showed more than +0.30 D post-task adaptation in the initial 10 s and exhibited significant reduction in monocular closed-loop AR error during the near task. These results suggest that TA adaptation may improve the accuracy of AR under closed-loop conditions.

The present study examined the potential impact of TA and near work induced TA-adaptation on the steady state AR. Most research groups have shown a large individual variability in their TA dataset similar to that of the original report from Leibowitz and coworkers (Leibowitz & Owens, 1975, 1978). Such variability is an important characteristic of dynamic biological system such as accommodation and vergence. Instead of looking at the group mean as a representative value, our approach has been to focus on the individual variability in different accommodative parameters and their correlations with each other. Accommodation responses during sustained monocular reading and to static targets at different viewing distances were compared to measures of baseline TA as well as post-reading TA adaptation. Under the vergence-accommodation dual-interaction model, the vergence system would have an obvious impact on closed-loop AR under binocular viewing conditions. To isolate the accommodative system and to focus on the pure influence of TA on steady state AR, most of our experiments were conducted under monocular conditions. To further test if vergence system involvement weakens this relationship, as shown previously by Miller, 1980, we also recorded AR during a sustained reading task under binocular conditions.

2. Method

2.1. Participants profile

Forty-two first year graduate students, age between 22 and 29 years-old (24.5 ± 1.8), were recruited from the Western University of Health Sciences student body over a one-year period of time by solicitation during a first-year orientation session. There were 27 female and 15 male subjects. Western University of Health Sciences is a private institution that consists of nine graduate level colleges of different health professions. All participants received and signed informed consent approved by the Institutional Review Board at Western University. The research followed the tenets of the Declaration of Helsinki.

All subjects were required to have a best-corrected monocular visual acuity of 20/25 or better, uncorrected (or residual) refractive error of $\leqslant$1.25 D hyperopia, $\leqslant$0.50 D myopia, $\leqslant$1.00 D uncorrected astigmatism or anisometropia. If correction was necessary for the subjects during the study, they were required to have habitual contact lens correction that had been prescribed and worn for a least one month. The requirement for contact lens correction during objective AR recording is necessitated by our study protocol of prolonged (10 min) continuous AR recording during reading task. The spectacle reflection resulted in excessive loss of data during auto-refraction recording. The residual uncorrected refractive error was determined by making three static auto-refraction recordings while participants viewed the 20/25 row of a Snellen chart at 6 m from the right-eye. Recordings were made under subjects' habitual viewing condition, either uncorrected, or wearing their habitual contact lens correction.

Major exclusion criteria for this study included history of treatment for binocular disorder, corneal refractive surgery, epilepsy or head trauma, multiple sclerosis, Graves's thyroid disease, myasthenia gravis, diabetes or Parkinson's disease. Participants were also ineligible if they were currently taking non-SSRI anti-anxiety drugs, anti-arrhythmic agents, anticholinergic or tri-cyclic antidepressants. Additionally, participants that were deaf or stuttering were excluded.

2.2. Objective accommodation response measure

All AR were measured monocularly from the right eye using the Grand Seiko WAM-5500, an open-field infrared auto-refractor (AIT Industries, Bensenville, IL, USA), set in either static recording mode or dynamic continuous recording mode. The left eye was occluded during the experiment unless otherwise stated. Although we did not directly monitor pupil size, the instrument limited data to be recorded only when pupil diameters were 3 mm or larger during recording (Mallen, Wolffsohn, Gilmartin, & Tsujimura, 2001), thus minimizing the effect of changes in pupil diameter on the AR. Calibration studies have shown the WAM to be accurate in both static and dynamic recording modes (Win-Hall & Glasser, 2009; Win-Hall, Houser, & Glasser, 2010).

Several different accommodation measures were made during an hour-long test session. First, measurement of monocular AR for static targets was recorded. The procedures had previously been described (Tosha, Borsting, Ridder, & Chase, 2009). A 2 cm target of high-contrast (Michelson = 79%) star symbol was presented at five viewing distances measured from the corneal plane in a