INVESTIGATING DYNAMICS OF DARK FOCUS OF THE HUMAN EYE IN YOUNG ADULTS

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Although the static behavior of accommodation in foveal vision has been well documented, the dynamic aspect of the resting state (dark focus) of accommodation is still unknown. In the present study, the accommodative dynamics of dark focus at the fovea is assessed objectively from a total of ten participants (five males and five females, aged 21-38 years) using the modified Shin-Nippon SRW-5000 autorefractor, a newly developed method to continuously monitor the accommodation process. Actual and potential applications of this study including specifications for designs are also discussed.

INTRODUCTION

Visual accommodation in humans has been studied extensively for more than a century. However, there is a paucity of literature on the dynamics of accommodation as a function of accommodative amplitude (Kasthurirangan, Vilupuru, & Glasser, 2003; Shirachi et al., 1978). Investigating dynamics as a function of amplitude provides important information about dynamic visual behavior and has been considered a powerful tool in understanding physiological changes (Bahill, Clark, & Stark, 1975; Heron, Charman, & Gray, 2002) as well as changes in the central neural processing delay of the aging eye (Lockhart & Shi, 2010).

Accommodation refers to the process by which the crystalline lens changes its optical power to maintain a clear image on the retina when focusing on objects at various distances. The dark focus, or resting level, of visual accommodation (Ebenholtz, 1992) is the refractive state to which the eye returns in the absence of visual stimulation, as in complete darkness (Allen & O'Leary, 2006; Simonelli, 1979; Toates, 1972). Interestingly, previous research shows that refractive error is minimal at the intermediate resting point of accommodation (Leibowitz & Owens, 1975, 1978; Owens, 1979), thus minimizing eye fatigue (Wesner & Miller, 1986).

As the measure of accommodation poses a high demand on the capability of test equipment, some of the instruments have shown limitations in measuring dynamic accommodation. One of these instruments is the Canon R-1 autorefractor, the most frequently used autorefractor in accommodation research. Because of its sensitivity to eye and head movements and pupil diameters (Wolffsohn, Gilmartin, Mallen, & Tsujimura, 2001), this machine is no longer available in the market, thus the use of the instrument may not accurately capture the dynamic accommodation process. Furthermore, most of the literature on accommodation thus far uses visual detection to manually select the onset/offset point of accommodation (Mordi & Ciuffreda, 2004; Sun et al., 1988), which may result in the failure to correctly determine these critical points of accommodation and also restrict the comparability of different studies. Therefore, the dynamic accommodative characteristics of human eyes remain unclear.

METHODS

Experimental Design

It was a repeated measures study design with ten participants. Each participant performed an active viewing task three times in a laboratory setting. Experimental protocol was reviewed and approved by the Institutional Review Board of Virginia Tech.

Independent variable. The lighting illuminance was set at 0 lux in a laboratory setting for scotopic vision.

Dependent variables. The amplitude (D) and velocity (D/s) values of accommodation were determined from the experiment using the modified autorefractor. The dark focus distance was then calculated from the measured amplitude of accommodation as given in equation (1).

$$\text{Dark focus (m)} = \frac{1}{\text{Amplitude of accommodation (D)}} \quad (1)$$

Based on completion of the study it was hypothesized that the range of dark focus distances (as measured by mean and variance) had wide variation among participants, but were highly stable for repeated measures of each participant.

Participants

A total of ten participants (five males and five females) with a mean age of 26.9±5 years (range 21 to 38 years) voluntarily participated in the study. Participants signed a consent form and completed a questionnaire regarding their personal information. They had normal or corrected-to-normal 20/20 vision. To ensure the qualification of the participant, a screening session was held prior to the actual test session. In addition, visual acuity and color vision tests were performed, using the Bausch & Lomb Vision Tester. Then, visual contrast sensitivity was tested using the VISTECH Vision Contrast Test System – Chart configuration B.

Apparatus

In this study, we used the modified Shin-Nippon SRW-5000 autorefractor, a new infrared open view autorefractor which is adjustable for proper ergonomic alignment (Wolffsohn, Hunt, & Gilmartin, 2002). This instrument is used to calculate refractive error of the human eye and has been found to be highly valid compared with subjective refraction and is repeatable in different age groups with pupil sizes ≥ 2.9 mm (Chat & Edwards, 2001; Mallen, Wolffsohn, Gilmartin, & Tsujimura, 2001). The modified autorefractor can be converted to give dynamic measurements of accommodation by continuous display of an infrared measurement ring and image analysis of the video output of the instrument. The measurement ring width correlates with the refractive error and utilizes edge detection techniques to achieve a resolution of < 0.01 D at 60 Hz (Wolffsohn, et al., 2002). The same edge detection techniques are also used to measure visual accommodative amplitudes. Knowing dark focus distance is equivalent to the inverse of accommodative amplitude, the purpose of this study is to determine dark focus distances by measuring accommodative amplitudes under scotopic vision.

Procedure and Experimental Setup

The experimental setup (see Figure 1) was such that the modified autorefractor was at 4 m away from the fixation target (see Figure 2) positioned at eye level. On arriving at the lab, participants gave informed consent and received a brief overview of screening tests and experimental methods.

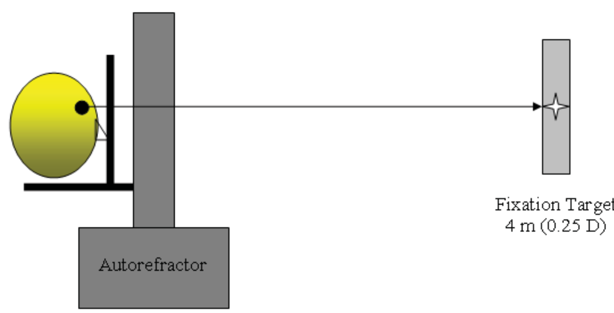

Figure 1. The experimental layout.

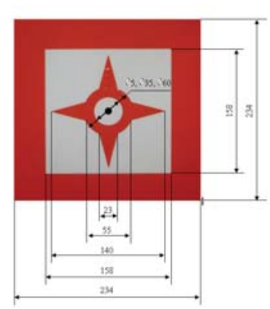

Figure 2. The fixation board (dimensions in millimeters).

After completing a screening session, participants were asked to sit at the modified autorefractor station with a separate desk for the PC to prevent the light from affecting the participants. The height of the chair and the chin rest of the modified autorefractor were adjusted for each individual. After paricipants found a comfortable sitting posture, the view window of the modified autorefractor was moved to the appropriate position relative to the eyes. Then participants were asked to keep their right eye open and the mearement ring of the modified autorefractor was positioned at the center of their retina. Before each trial the participant's head was positioned upright by observing the actual head inclination angle between the horizontal and the ear-eye line, known as Reid's base line.

During perfoming the active viewing task, participants were instructed to keep their gaze directed horizontally to a fixation target on the wall and maintain at the same position. After a period of ten minutes for full dark adaptation, accommodative responses (amplitude: D, and velocity: D/s) of participant's right eye were measured objectively with the modified autorefractor. Dark focus distance was then calculated from the measured amplitude of accommodation. Three trials of thirty-second duration were collected. One measure of dark focus accommodation was determined for each trial by averaging three consecutive seconds during which the accommodation signal was most stable. An one-minute break was given to participants after each trial.

Data Recording, Processing, and Analysis

Accommodative responses and the dark focus distances were calculated from the sphere-equivalent power obtained from the modified autorefractor. The original use of the autorefractor is to measure the refractive errors of the human eye by positioning a measurement ring target of infrared light on the participant's eye and measuring the refracted image by laterally moving the Badal lens to find the optimal focus of the ring image on the retina.

After the shape and size of the ring image has been determined from different eye conditions, the refractive error was then identified. Data was collected by a Pentium IV 2.40 GHz PC with a National Instrument (NI) PCI-1407 image acquisition card via the output panel of the autorefractor. Data was analyzed via threshold image analysis to obtain the diameter of the measurement ring by using LabVIEW 8.0 programming and NI Vision Module 8.0.1 software from Texas National Instrument. The diameter value was calculated as the spherical equivalent (SE) (Shi & Lockhart, 2007). As accommodation can be observed by optical power changes, the change of SE indicated the accommodative responses. Since SE is linearly related to the ring diameter, a conversion equation could be formed based on static and dynamic accommodative responses of the eye, which provide 60 Hz temporal resolution. The dynamic accommodation process can be calculated to an accuracy of <0.001 D (Wolffsohn, et al., 2001).

RESULTS

Data for the present study was acquired using a modified autorefractor. Savitzky-Golay filtering was then used to analyze the data obtained from the modified autorefractor. An example of the data collected is shown in Figure 3. These accommodation signals were recorded as the participant focused her gaze on the fixation target located 4 m from the eyes. The average amplitude of accommodation was 1.59 (0.06) D, the dark focus distance was 0.63 m, and the average velocity of accommodation was -0.0005 (0.0044) D/sec.

Overall, mean and standard deviation of dark focus distance obtained in this study from ten participants were 0.68 m and 0.09 m, respectively. As compared with the previous results of Leibowitz & Owens (1975), the mean dark focus distance from our study was slightly greater (0.68 m vs 0.58 m), but the standard deviation of dark focus distance was much smaller (0.09 m vs 1.38 m). Results of the present study also confirmed the previous findings that dark focus position was highly stable for an individual's test-retest results (Heron, Smith, & Winn, 1981).

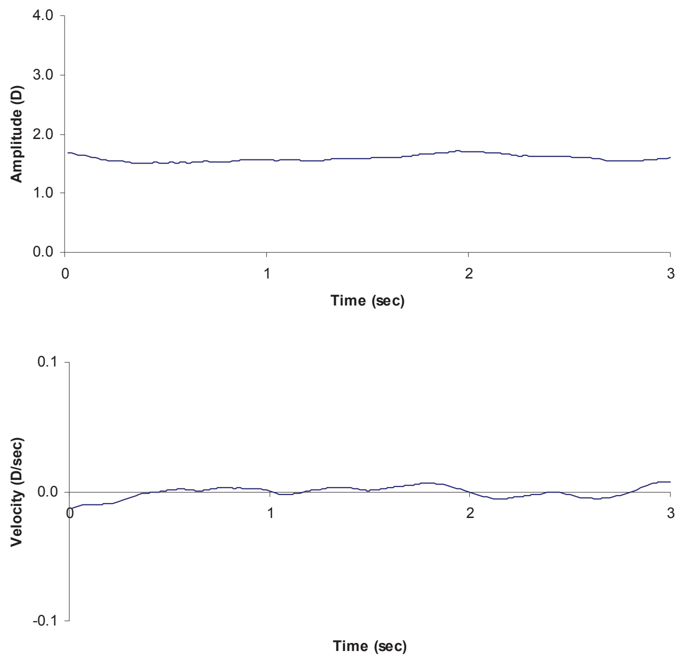

Figure 3. A sample dark focus amplitude and velocity of an active viewing task.

Statistical Analysis

JMP Statistical Software was used for analyses of variance (ANOVAs) with repeated measures. Statistical significance was set at $\alpha = 0.05$. There was no significant difference between dark focus distances within participants for repeated measures ($F > 0.613$). Also, dark focus distances were not significantly different between participants ($F > 0.096$).

DISCUSSION

After data collection and analysis, we found that dark focus distances didn't vary between young adults. Our findings disagreed with previous studies found that the intermediate dark focus distances have wide variation among individuals (Leibowitz & Owens, 1975, 1978; Ripple, 1952). However, it might support the previous report that the values of accommodative response and dark focus position were dependent on the method used to measure them (Heron, et al., 1981).

For practical application, the knowledge of dark focus and conditions suggest possible corrective techniques, the most obvious of which is the design of corrective lenses. However, general guidelines on universal corrections for night vision have not been completely satisfactory due to the variability in dark focus (Simonelli, 1979). Therefore, using individualized corrections equivalent to dark focus would be an additional correction resulting in higher sensitivity in detecting a target under low illuminance, such as while driving at night (Fejer, 1995).

FUTURE WORK

It was necessary to address that findings of the present study were derived from ten participants in a young age group. Future studies with a larger number of participants in different age groups should be considered and may produce more conclusive results regarding the discriminative capacity of dynamics of accommodative stability measures. Additionally, other factors such as individual's stress level, physical fatigue, target luminance levels, and ambient lighting conditions may play a role in one's accommodative stability and should be considered in future studies.

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