Near Work, Visual Fatigue, and Variations of Oculomotor Tonus

D. Alfred Owens and Karen Wolf-Kelly

One hour of near work produced adaptive changes in the resting states of accommodation and binocular vergence, which may be responsible for different aspects of visual fatigue. Two groups of college students read from either hard copy or a video display terminal (VDT). Immediately before and after reading, the subjects' distance acuity, dark vergence, dark focus, and accommodative response accuracy for a monocular stimulus were measured. After reading, subjects also rated their subjective feelings of visual fatigue. Reading produced significant changes in both accommodation and vergence, which did not differ for the hard copy and VDT modes of presentation. Dark focus and accommodative responses shifted in the myopic direction by an average of 0.6 D and at least 0.35 D, respectively; dark vergence distance shifted in the convergent direction by an average of 11.4 cm. These changes were greatest for subjects whose initial resting postures corresponded to a far distance. After reading, one third of the subjects exhibited lower visual acuity at distance. This change was significantly correlated with changes in dark focus ($r = 0.35$) but not with changes in dark vergence ($r = -0.12$). In contrast, subjective ratings of visual fatigue were not correlated with changes in the dark focus ($rho = 0.13$), but they were significantly correlated with changes in dark vergence ($rho = 0.58$). These findings indicate that ordinary near work can produce significant changes in the resting states of accommodation and vergence, whose magnitude depend on the subject's initial oculomotor resting tonus. They also suggest that changes of tonic vergence are specifically related to feelings of eyestrain, while changes of tonic accommodation are related to blurred distant vision following near work. Invest Ophthalmol Vis Sci 28:743–749, 1987

Near work has long been considered a potential source of visual problems. As early as 1713, the epidemiologist, Ramazzini[1] reported that prolonged near work produces "weakness of vision" including myopia and changes in "tonus of the membranes and fibers of the eye . . ." His observation has been confirmed by many artisans, office workers, and scholars who have experienced blurred vision, eyestrain, and headaches after prolonged work. With the advent of video display technology, there has been a resurgence of interest in these problems.[2–5] Yet, despite the pervasive opinion that near work is stressful and potentially deleterious to the eyes, scientific evidence for such effects is inconclusive, and the mechanisms responsible for symptoms of visual fatigue remain obscure.

From the Whitely Psychology Laboratories, Franklin and Marshall College, Lancaster, Pennsylvania.

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Reprint requests: D. A. Owens, the Whitely Psychology Laboratories, Franklin and Marshall College, P. O. Box 3003, Lancaster, PA 17604-3003.

Recent research on the resting states of accommodation and vergence suggested a new approach to visual problems associated with near tasks. A major insight from this research is that, contrary to traditional theories,[6,7] the physiological resting (tonus) states of accommodation and vergence correspond to an intermediate posture rather than the far point of their operating range.[8] On the average, the tonus positions, which we refer to as "dark focus" and "dark vergence," correspond to distances of about 67 cm (1.5 diopters, D) and 120 cm (0.8 meter-angles), respectively.[9,10] Another key finding is that both resting states exhibit wide individual differences that are not detected by standard clinical examinations, but are related to variations in oculomotor and perceptual performance.[8–11] For example, under many viewing conditions, including text displays on hard copy, microfiche, and VDT's,[12,13] accommodation responses are strongly biased toward the subject's characteristic resting posture. It is possible that individual differences in oculomotor resting tonus are also related to one's susceptibility to problems associated with near visual tasks.

Consistent with this hypothesis, there is growing evidence that strenuous visual tasks induce changes of oculomotor tonus. Early clinical studies showed that prism duction tests produce variations in lateral phoria that are thought to reflect changes in tonic vergence.[14-16]

Later research has shown that perceptual adaptation to base-out prisms or to sustained near fixation is also accompanied by changes in dark (tonic) vergence.[17-20] Similarly, several studies have shown that prolonged strenuous accommodation causes a shift of the resting focus in the direction of the previous effort.[21-24] These studies indicate that changes in the resting state increase as the distance of the visual task departs from the subject's resting distance, and they suggest that such changes may serve to reduce oculomotor effort and improve response accuracy for the task. It is not clear, however, whether adaptive changes of oculomotor resting tonus are related to the subject's initial resting state or to symptoms of visual fatigue, such as blurred vision and asthenopia.

The current study investigated the effects of reading, from either hard copy or a video display terminal (VDT), on (1) the resting states of accommodation and vergence, (2) accommodative response accuracy, (3) subjective feelings of visual fatigue, and (4) visual acuity for a distant target. A relatively large sample of subjects was tested in order to evaluate whether individual differences in the resting states of accommodation and vergence can help to clarify the effects of near work on visual performance and discomfort.

Materials and Methods

Subjects

Twenty-eight college students, aged 17 to 22 yr (Mean = 20 yr), served as subjects. To obtain a representative sample of the college population, no specific visual criteria limited subject selection. None of the subjects claimed to have unusual problems with reading or near work, and all wore their normal refractive correction throughout the experiment.*

Apparatus

Reading material was selected from an introductory psychology textbook (Gleitman, 1981) and was presented at a distance of 20 cm either as the original hard copy or a video display (Lear Siegler ADM-31, Bensalem, PA). The top of the page or screen was positioned approximately at eye level, and a chin rest was used to maintain stable head position. Hard copy was viewed under flourescent room illumination. Lower-case letters subtended 24 × 31 min of arc, page luminance was 16 cd/m^2, and contrast (Lmax − Lmin/ Lmax + Lmin) between the text and page was 0.77. Lower-case letters on the VDT subtended 43 × 60 min, screen luminance was 20 cd/m^2, and the contrast between the white letters and the gray screen was 0.53.

The dark focus and accommodative responses were measured with a polarized vernier optometer[25,26] that required subjects to judge the alignment of two adjacent horizontal line segments, each subtending approximately 32 × 12 min of arc. An electronic timer limited exposure duration of the optometer test target to 0.5 sec. The accommodative stimulus was a matrix of 9 tumbling E's, with critical details of 15 min of arc. The stimulus was a high-contrast photographic transparency viewed monocularly in a Maxwellian view optical system at optical distances of 0, 0.5, 2.0, 3.0, and 4.0 D. These stimuli were viewed through a 3.5 mm artificial pupil that contained crossed polaroids for the vernier optometer. The tungsten source for the Maxwellian view stimulus channel illuminated a circular opal glass secondary source that was 6.5 mm in diameter and was imaged in the plane of the artificial pupil.

Dark vergence was measured by subjective alignment of two dichoptic stimuli, flashed intermittently for 100 msec in total darkness. The stimuli were created by a point light source, which was mounted on a track that extended along the subject's median plane to a distance of 367 cm. A red Maddox (American Optical, Southbridge, MA) rod was positioned before the subject's left eye. When the light point was flashed, the subject saw a red vertical streak with the left eye and a bright white point with the right eye. The dark vergence posture was defined as the distance of the light source when the red streak and the white point appeared to be superimposed. This technique is similar in principle to clinical measures of phoria with the important difference that no accommodative stimuli were present.†

* It is possible that the subjects' current refractive corrections were not optimal, since refractive errors are known to change during early college years. Nonetheless, we believe that large uncorrected refractive errors are not characteristic of our sample. Twenty-two of the subjects demonstrated acuities of 20/20 or better with a standard wall chart (20 ft); five subjects scored 20/30, and the remaining subject scored 20/70. Measures taken with the vernier optometer indicated that the last subject was an uncorrected myope. Removing her data from the sample produced no changes in statistical outcomes or interpretations. Acuity measures would be insensitive to uncorrected hyperopia. However, such refractive errors are judged to be unlikely for two reasons: (A) Measurements of refraction obtained with the vernier optometer while the subjects viewed a matrix of Snellen E's presented at optical infinity showed that all subjects tended to be somewhat myopic. (B) A subsequent study, in which we obtained professional refractions of 43 subjects who were recruited in the same way as the present sample, found only three students (7%) who were uncorrected hyperopes, and these were all less than +1.0 D.

† Previous studies have shown that a bright point of light[27] or a bright streak of light[28] are not effective stimuli for accommodation, even when viewed for unlimited duration. Thus, the dark vergence test stimuli, whose exposure duration was considerably shorter than the reaction time of accommodation, minimized the possibility of an accommodative response and the resultant accommodative vergence.

Black draperies were used to shield the vernier optometer, Maxwellian view stimulus channel, and dark-vergence apparatus from the subjects' view.

Procedure

After describing the experimental procedure, informed consent was obtained individually from each subject, and he/she was randomly assigned to one of two groups. One group read for 1 hr from hard-copy, and the other group read the same text for the same duration from the VDT. In both cases, the text was viewed binocularly in a normally illuminated room. Subjects were informed that they could terminate their participation early without penalty. Four subjects exercised this option, terminating their reading period 10–15 min early. All subjects agreed to complete the post-reading measures.

The subjects' dark vergence, dark focus, accuracy of accommodative responses for a monocular stimulus, and visual acuity (wall chart at 20 ft) were measured immediately before and after the reading task. All measurements of accommodation and dark vergence were obtained by a bracketing technique in which the test target was positioned unpredictably nearer or farther than the subject's current response level. On each presentation of the test stimulus, the subject indicated the relative alignment of the components of the test stimulus. The position of the test stimulus was varied over successive presentations until the subject indicated that stimulus components appeared to be aligned. This procedure was repeated three times, and the mean of the three settings achieving subjective alignment was used as that subject's accommodation or vergence measurement. The order of accomodation and vergence measurements was counterbalanced across subjects, and the order of accomodative stimulus distances was randomized. Acuity was measured following the oculomotor tests. All experimental measures were completed in 15–20 min.

After completion of all experimental measures, each subject was asked to rate on a scale of 1–7 her/his level of visual fatigue. Ratings of 1 indicated no perceptible fatigue, while 7 indicated extreme fatigue. No attempt was made to suggest specific symptoms of visual fatigue, although subjects who expressed uncertainty were encouraged to rate feelings of eyestrain and not to consider general fatigue or sleepiness.

Results

Analyses of variance were used to compare the magnitude of changes in dark vergence, dark focus, and accommodative responses for the two groups of subjects (hard copy vs VDT readers). No significant differences or notable trends were found for any of these variables, and therefore, the data from both groups were

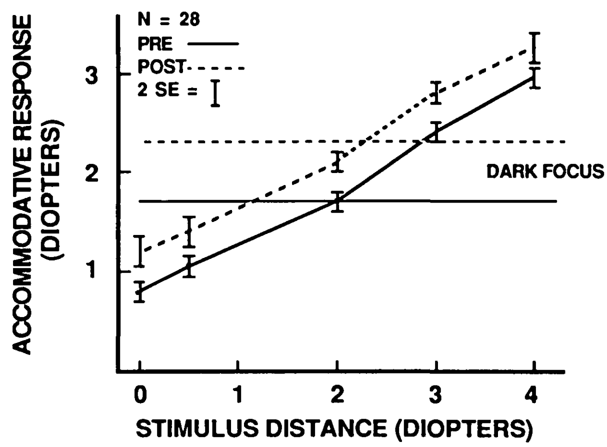

Fig. 1. Mean dark focus and accommodative response functions before (solid lines) and after (dashed lines) subjects read for 1 hr at a distance of 20 cms. Both the dark focus and accommodative responses showed significant shifts in the myopic direction. Vertical bars indicate two standard errors of the means. Linear regressions showed that the mean accommodative response functions before and after reading were $f(x) = 0.54x + 0.76$ ($r^2 = 0.992$) and $f(x) = 0.52x + 1.16$ ($r^2 = 0.994$), respectively.

combined. Analyses of the combined data revealed significant changes in both resting (tonus) positions following reading. The mean dark focus shifted in the myopic direction from 1.70 ± 0.16 to 2.31 ± 0.18 D ($t = 4.58$, $df = 27$, $P < 0.001$), and the mean dark vergence distance shifted from 83.5 ± 6.8 to 72.1 ± 6.1 cm ($t = 3.74$, $df = 27$, $P < 0.001$). For individual subjects, the magnitude of changes in dark focus and dark vergence (in meter angles) were not significantly correlated ($r = 0.06$; $t = 0.31$, $df = 26$, $P > 0.50$).

As illustrated in Figure 1, the myopic shift of the dark focus was accompanied by a similar displacement of the entire accommodative response function [$F(1,27) = 39.6$; $P < 0.001$]. After reading, accommodative responses for the matrix of Snellen E's were at least 0.3 ± 0.16 D more myopic at every stimulus distance. This change of focusing behavior is particularly interesting for the target at infinity (0D). This measure represents the average (monocular) far point, with the subjects' normal refractive correction in place and, therefore, can be compared with conventional measures of refractive error. The mean far point shifted 0.43 ± 0.09 D in the myopic direction.

In addition to the shifts of dark focus and accommodative response levels, it was of interest to examine whether reading affected the gain of accommodation. For steady-state accommodation, the best index of accommodative gain is given by the slope of the stimulus-response function.[8,9] These values were obtained by fitting linear functions to the data illustrated in Figure 1 by the method of least squares. The resulting accommodative response function for measures taken before reading was $f(x) = 0.54x + 0.76$ ($r^2 = 0.992$), and that for measures taken after reading was $f(x) = 0.52x$

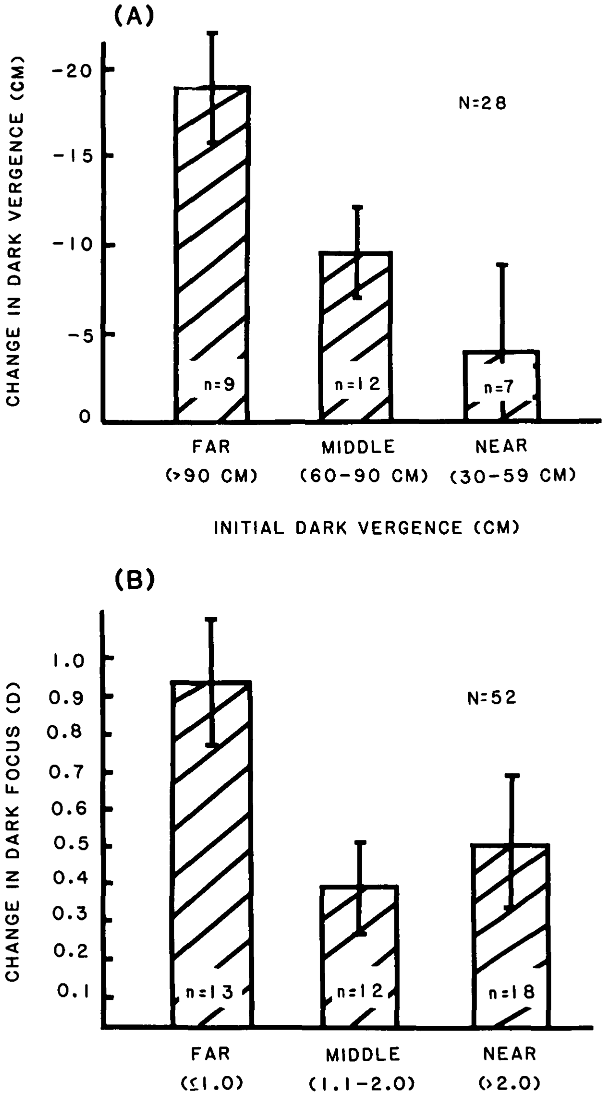

Fig. 2. Histograms illustrating the change in resting positions of accommodation and vergence after reading. Vertical bars indicate two standard errors of the means. For both accommodation (A) and vergence (B), the changes induced by reading were greatest for subjects whose resting posture initially corresponded to a far distance.

+ 1.16 ($r^2 = 0.994$). The similar slope values (0.54 and 0.52) indicate that there was no change in response gain, while the change in intercept values (0.76 to 1.16) is consistent with the myopic shift of the resting focus.

Figure 2 shows that changes in (A) dark vergence and (B) dark focus were greater for subjects whose initial resting state (ie, before reading) was categorized as far than for those whose resting state was categorized as near. To evaluate these individual differences statistically, subjects were divided into three groups according to their initial resting postures. Descriptive statistics for categorization criteria and the magnitudes of changes in dark vergence and dark focus are given in Table 1. Because of differences in their initial resting postures, half of the subjects were categorized in different groups, although there was a significant overall correlation between initial dark focus and dark vergence values (converted to meter angles; $r = 0.43$; $t = 2.43$, $df = 26$, $P < 0.05$).

Data from 24 additional subjects were included in analyses of the effects of reading on the dark focus, raising the N from 28 to 52. These subjects had been tested in another experiment under conditions essentially identical to those of the textbook reading group, except that fatigue ratings were not collected and distance acuity was measured with a Bausch & Lomb (Rochester, NY) Ortho-Rater. Analyses of variance of both the dark vergence ($N = 28$) and the dark focus ($N = 52$) data showed significant interactions between initial resting posture (far, middle, near) and time of measurement (pre- vs post-reading), indicating that reading induced greater changes in far subjects than in near subjects [dark vergence: $F(2,25) = 5.11$; $P < 0.025$; dark focus: $F(2,49) = 3.46$; $P < 0.05$]. Although similar trends were evident for the dark focus data of both the smaller ($N = 28$) and combined ($N = 52$) samples, the interaction between initial resting focus and time of measurement was not statistically significant for the smaller sample.

One third of the subjects (17 of 52) exhibited reduced visual acuity at distance following reading. Point-biserial correlational analyses showed that losses of visual acuity were significantly correlated with myopic shifts of the dark focus ($r_{pb} = 0.35$; $t = 2.64$; $df = 50$; $P < 0.01$), but losses of visual acuity were not related to changes of dark vergence distance ($r_{pb} = -0.12$; $t = -0.92$; $df = 50$; $P > 0.10$).

Most subjects indicated that they experienced moderate levels of visual fatigue after reading, with 15 rating their level of fatigue at 5 on a scale of 1–7. The mean fatigue rating was 4.75 ± 0.22. Spearman rank-order correlations were computed to determine whether the subjective ratings were related to changes in the resting state of accommodation or vergence. These comparisons, illustrated in Figure 3, showed that visual fatigue ratings were not correlated with changes in the dark focus ($rho = 0.13$; $t = 0.67$, $df = 26$, $P > 0.50$), however they were significantly correlated with changes in dark vergence distance ($rho = 0.58$; $t = 3.63$, $df = 26$, $P < 0.002$). This implies that subjects who exhibited relatively large changes in dark vergence distance also tended to report greater levels of visual fatigue.

Product-moment correlational analyses showed that the standard error for predicting a subject's fatigue rating on the basis of her/his change in dark vergence is 0.9 on our 7-point scale. This predictive capability is limited at least partly by the subjective (ordinal) measure of fatigue. Additional analyses indicated that the fatigue ratings were not significantly correlated with

Table 1. Classification of subjects according to their initial resting postures, and mean change of dark vergence distance and dark focus for each group

	Dark vergence distance (N = 28)			*Dark focus (N = 28)*			*Dark focus (N = 52)*		
	N	*Range of initial values*	*Mean change cm*	*N*	*Range of initial values*	*Mean change cm*	*N*	*Range of initial values*	*Mean change (D)*
Far	9	91–176 cm	−19.3 cm	6	<1.0 D	1.01 D	13	<1.0 D	0.93 D
Mid	12	60–90 cm	−9.6 cm	14	1.1–2.0 D	0.46 D	12	1.1–2.0 D	0.38 D
Near	7	30–59 cm	−4.2 cm	8	>2.0 D	0.56 D	18	>2.0 D	0.50 D

* Analyses of variance showed significant interactions between initial resting posture and time of measurement (pre- vs post-reading) for dark vergence and the larger dark focus sample. Although a similar trend is evident, this interaction is not statistically significant for the smaller dark focus.

initial dark vergence distance (rho = 0.24; t = 1.26, df = 26, $P > 0.20$) nor with initial dark focus (rho = 0.36; t = 2.03, df = 26, $P > 0.05$). Also, there was no significant difference between the average fatigue rating given by the far dark vergence group (N = 9, $\bar{X} = 5.1$) and the far dark focus group (N = 6, $\bar{X} = 4.5$).

Discussion

The present findings show that reading ordinary text at a near distance for 1 hr induces significant changes in the resting postures of both accommodation and vergence. Moreover, they indicate that (1) changes of oculomotor tonus depend on the subject's initial resting state and (2) variations of accommodative and vergence tonus may be related to dissociable symptoms of visual fatigue.

Similar to previous studies, which generally used less commonplace tasks, both the dark focus and dark vergence positions shifted toward the distance of the visual task. Individual differences in the magnitude of these adaptive changes are quite large and are of particular interest in the context of visual fatigue. Our results show that subjects whose initial resting posture corresponded to a relatively far distance exhibited significantly greater aftereffects than those with a near resting state. This outcome, which was recently confirmed by Ebenholtz in a study of accommodative hysteresis,[29] indicates that variations of oculomotor tonus depend on the difference between the distance of the visual task and the individual's characteristic resting posture. This interpretation implies that oculomotor effort should be scaled relative to the individual's dark focus or dark vergence posture rather than to the far point or optical infinity.

These findings also suggest an explanation for inconsistencies of previous research. Some early studies reported that near work induces a recession of the near points of accommodation or vergence,[30–32] while others found no change or an approach of the near points.[33–35] Such discrepancies have been difficult to interpret, because the methods employed differed widely. However, these studies shared two common features: (1) they tested relatively small samples of subjects, and (2) they did not assess oculomotor tonus. It is possible that individual differences in the resting states of accommo-

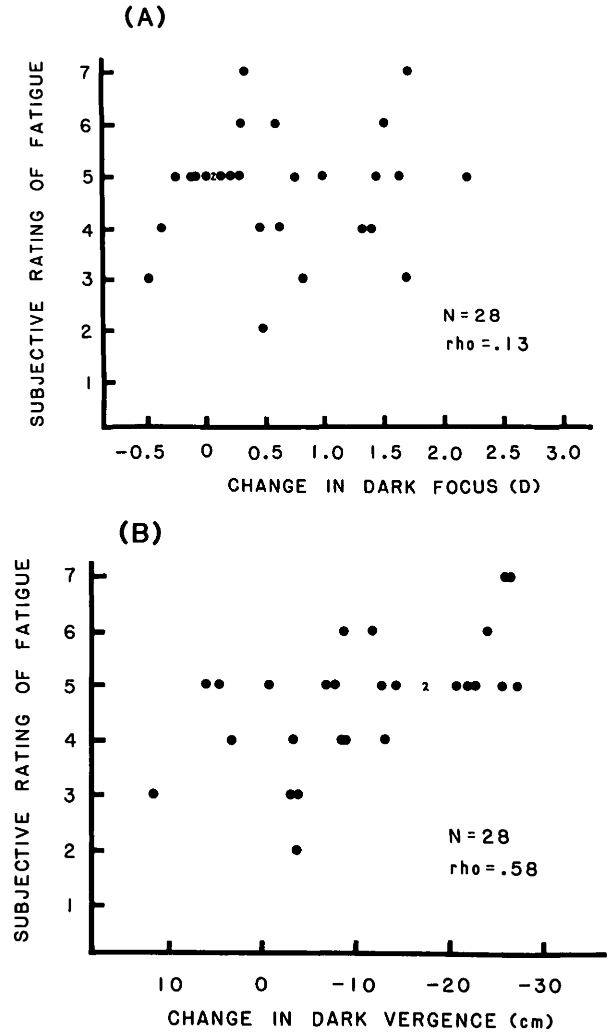

Fig. 3. Scatter diagrams illustrating the relationship between individual subjects' ratings of visual fatigue after reading and the magnitude of changes in their dark focus (A) and dark vergence (B) induced by reading. While there was no statistically significant relation between changes in dark focus and fatigue, changes in dark vergence distance were significantly correlated with subjective ratings of visual fatigue.

dation and vergence among the various samples are responsible for the discrepant findings.

Our results also suggest that the adaptive variations of accommodative and vergence tonus may have important consequences for visual comfort and performance. Although subjective blur was not assessed, the data in Figure 1 show that the myopic shift of the dark focus was accompanied by a similar shift of accommodative responses for a monocular high-contrast stimulus. Depending on stimulus distance and pupillary diameter, the mean change in far point (0.43 D) could produce appreciable blur. This would account for the reduced visual acuity for a distant (20 ft) wall chart experienced by many subjects after reading. Generalization to naturalistic conditions must be tentative, however, because (1) the accuracy or gain of accommodation responses for our monocular target was rather low, and (2) accommodation for binocular stimuli was not tested. The Hung-Semmlow[36] model of accommodative control, for example, predicts that accommodative myopia associated with a shift of resting tonus would be less dramatic for stronger binocular stimuli.

Nevertheless, there is reason to suspect that the currently reported changes of dark focus are representative and would be related to general changes in focusing behavior. Although the response gains illustrated in Figure 1 are low, they are typical for naive subjects viewing a monocular stimulus in Maxwellian-view optics. In a study of 69 young adults,[37] we found that accommodative response gain, defined in terms of the slope of accommodative response functions for the same monocular stimulus used in this experiment, was 0.57 ± 0.02, which compares closely with the present values. Moreover, there is evidence that accommodation is often imprecise under naturalistic viewing conditions.[8,9,37] Of particular relevance are studies showing that accommodation for various text displays tends to be biased toward the individual's characteristic dark focus.[12,13] On this basis, one would expect adaptive variations of the dark focus to result in concomitant changes of accommodation for text displays as well as other commonplace stimuli. The uncertainty of this conclusion highlights the need for further research on accommodative behavior of unpracticed subjects under naturalistic viewing conditions.

Objective evaluation of asthenopia and specification of its underlying causes have proven to be elusive and persistent problems for visual science. The present study did not resolve these problems, but it did reveal an intriguing dissociation that may be a valuable lead for further investigation. Adaptive changes of the dark focus were correlated with reduced visual acuity at distance, but they were not correlated with subjective ratings of visual fatigue. Conversely, adaptive changes of dark vergence were correlated with ratings of visual fatigue, but they were not correlated with changes of visual acuity.

It is important to note that the effects of reading on dark vergence and dark focus were not even weakly correlated ($r = 0.06$). This supports the hypothesis that accommodation and vergence tonus are determined by independent mechanisms,[10,38,39] and it is consistent with the notion that they may mediate different aspects of asthenopia. It would be premature, however, to conclude that changes in tonic vergence will account completely for the visual discomforts associated with near work, and that changes in tonic accommodation will explain all instances of blurred vision. The truth is likely to be more complicated because of the well-known interactions of the accommodation and vergence systems. Variations of the resting tonus of either system are likely to influence these interactions (ie, the AC/A and CA/C synergies), and further research is necessary to explore the consequences of such effects for problems of near work.

In view of recent concerns regarding the use of VDT's, it is of interest that we found no difference between the effects of reading from hard copy or a VDT. The lack of a difference should be interpreted with caution, however. Our study imposed the same postural and viewing constraints on book readers as on VDT readers, but under normal working conditions, such materials are often viewed quite differently. Hard copy is more amenable than VDT's to variations of viewing distance and posture, and in many situations, near tasks last considerably longer than our 1 hr experimental exposure. Furthermore, problems encountered with VDT's may depend on display characteristics such as glare, contrast, flicker, or jitter, which were not varied in this study. Our findings do not rule out the possibility of special problems with VDT's under typical working conditions.

In summary, the current data provide new evidence that near reading induces significant changes in the resting tonus of accommodation and binocular vergence, with both systems tending to adopt a nearer resting posture after reading. The magnitude of these adaptive changes depends on the individual's initial resting posture; subjects who initially have a far resting posture tend to exhibit greater oculomotor adaptation. Although both accommodative and vergence tonus tend to shift in the same direction as a result of near work, these changes are not correlated, and they may be responsible for dissociable visual symptoms associated with near work. The present findings suggest that changes of tonic accommodation contribute to blurred vision at distance, while changes of tonic vergence are more specifically related to subjective feelings of visual fatigue or eyestrain.

Key words: oculomotor tonus, visual fatigue, accomodation, vergence, individual differences, dark focus, dark vergence, near work

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References

1. Ramazzini B: Diseases of Workers. (translated by WC Wright) Chicago, Univ. of Chicago Press, 1940, 1713, pp. 323–325, 415–419.
2. Tabor M: Video display terminals: The eyes have had it! Occup Health Saf, Sept. 1981, 30.
3. Smith AB, Tanaka S, Halperin W, and Richards RD: Correlates of ocular and somatic symptoms among video display terminal users. Hum Factors 26:143, 1984.
4. Brown BS, Dismukes K, and Rinalducci EJ: Video display terminals and vision of workers: Summary and overview of a symposium. Behav Information Technol 1:121, 1982.
5. Video Displays, Work, and Vision, Washington, DC, National Academy Press, 1983, pp. 143–172.
6. Helmholtz H: *Handbuch der physiologischen Optik,* Leipzig, Voss, 1867, pp. 90–123. Or see English translation of 3rd ed. by Southall JPC, New York, Dover, 1962, pp. 136–137; 143–166.
7. Maddox EE: The Clinical Use of Prism, 2nd Ed. Bristol, England, John Wright & Sons, 1893, pp. 83–92.
8. Owens DA: The resting state of the eyes. Am Scientist 72:378, 1984.
9. Leibowitz HW and Owens DA: New evidence for the intermediate position of relaxed accommodation. Doc Ophthalmol 46: 133, 1978.
10. Owens DA and Leibowitz HW: Perceptual and motor consequences of tonic vergence. *In* Vergence Eye Movements: Basic and Clinical Aspects, Schor C and Ciuffreda K, editors. Boston, Butterworths. 1983, pp. 25–74.
11. Francis EL and Owens DA: The accuracy of binocular vergence for peripheral stimuli. Vision Res 23:13, 1983.
12. Murch G: How visible is your display? Electro-Opt Sys Design, March, 1982, pp. 43–49.
13. Kintz RT and Bowker DO: Accommodation response during a prolonged visual search task. Appl Ergonom 13:55, 1982.
14. Alpern M: The after effect of lateral duction testing on subsequent phoria measurements. Am J Optom Arch Am Acad Optom 23: 442, 1946.
15. Morgan MW: The direction of visual lines when fusion is broken as induction tests. Am J Optom Arch Am Acad Optom 24:8, 1947.
16. Carter DB: Fixation disparity and heterophoria. Am J Optom Arch Am Acad Optom 42:141, 1965.
17. Owens DA and Leibowitz HW: Accommodation, convergence, and distance perception in low illumination. Am J Optom Physiol Opt 57:540, 1980.
18. von Hofsten C: Recalibration of the convergence system. Perception 8:37, 1979.
19. Ebenholtz SM: Hysteresis effects in the vergence control system: Perceptual implications. *In* Eye movements: Cognition and Visual Perception, Fisher DF, Monty RA, and Senders JW, editors. Hillsdale, NH, Erlbaum, 1981, pp. 83–94.
20. Ebenholtz SM and Fisher SK: Distance adaptation depends on plasticity in the oculomotor control system. Perception Psychophys 31:551, 1982.
21. Ostberg O: Accommodation and visual fatigue in display work. *In* Ergonomic Aspects of Visual Display Terminals, Grandjean E and Vigliani E, editors. London, Taylor & Francis, 1980, pp. 41–52.
22. Ebenholtz SM: Accommodative hysteresis: A precursor for induced myopia? Invest Ophthalmol Vis Sci 24:513, 1983.
23. Miller RJ, Pigion MF, Wesner MF, and Patterson JG: Accommodation fatigue and dark focus: The effects of accommodation-free visual work as assessed by two psychophysical methods. Perception Psychophys 34:532, 1983.
24. Schor CM, Johnson CA, and Post RB: Adaptation of tonic accommodation. Ophthal Physiol Opt 4:133, 1984.
25. Moses RA: Vernier optometer. J Optom Soc Am 61:1539, 1971.
26. Simonelli NM: Polarized vernier optometer. Behav Research Methods Instrumentation 12:293, 1980.
27. Owens DA and Leibowitz HW: The fixation point as a stimulus for accommodation. Vision Res 15:1161, 1975.
28. Owens DA, Mohindra I, and Held R: The effectiveness of a retinoscope beam as an accommodative stimulus. Invest Ophthalmol Vis Sci 19:942, 1980.
29. Ebenholtz SM: Accommodative hysteresis: Relation to resting focus. Am J Optom Physiol Opt 62:755, 1985.
30. Luckiesh M and Moss FK: Fatigue of convergence induced by reading as a function of illumination intensity. Am J Ophthalmol 18:319, 1935.
31. Berens C and Sells SB: Experimental studies of fatigue of accommodation I. Plan of research and observations on recession of near point of accommodation following a period of interpolated work on the ophthalmic ergograph. Arch Ophthalmol 31:148, 1944.
32. Brozek J, Simonson E, and Keys A: Changes in performance and in ocular functions resulting from strenuous visual inspection. Am J Psychol 63:51, 1950.
33. Kurtz JI: An experimental study of ocular fatigue. Am J Optom Arch Am Acad Optom 15:86, 1938.
34. Lancaster WB and Williams ER: New light on the theory of accommodation with practical applications. Trans Am Acad Ophthalmol Otolaryngol 19:170, 1914.
35. Brozek J, Simonson E, Bushard WJ, and Peterson JH: Effects of practice and the consistency of repeated measurements of accommodation and vergence. Am J Ophthalmol 31:191, 1948.
36. Semmlow JL and Hung GK: The near response: Theories of control. *In* Vergence Eye Movements: Basic and Clinical Aspects, Schor C and Ciuffreda K, editors. Boston, Butterworths, 1983, pp. 175–195.
37. Owens DA: Oculomotor performance in low visibility conditions. *In* Proceedings of the Tri-Service Aeromedical Research Panel, Monaco, WA, editor, Naval Aerospace Medical Research Laboratory, Naval Air Station, Pensacola, FL 1984.
38. Owens DA and Wolf KS: Dissociation of the dark focus and tonic vergence by near work. ARVO Abstracts. Invest Ophthalmol Vis Sci 25(Suppl):183, 1984.
39. Kotulak JC and Schor CM: The dissociability of accommodation from vergence in the dark. Invest Ophthalmol Vis Sci 27:544, 1986.