Optical Compensation for Night Myopia Based on Dark Focus and CA/C Ratio

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Purpose. To determine whether individual differences in dark focus and convergence accommodation to convergence (CA/C) ratio can be used to prescribe the best optical correction for night myopia.

Methods. The best correction for night myopia was obtained by measuring visual acuity and contrast sensitivity across a range of lens powers and luminances. Dark focus was measured with an infrared optometer, and CA/C ratio was measured with an infrared optometer and eyetracker. Only young subjects were used (mean age = 25.4 years).

Results. Optimal lens power was significantly correlated with dark focus, regardless of CA/C ratio. However, the slope of the regression line relating lens power to dark focus was steeper for subjects with CA/C ratios less than 0.4 diopters/meter angle (D/MA, $n = 7$) than for subjects with CA/C ratios greater than 0.4 D/MA ($n = 9$). The mean CA/C ratio for the entire sample ($n = 16$) was 0.59 D/MA. The mean optimal lens power and dark focus were -0.79 and 0.74 D, respectively, for the low CA/C group, and -0.60 and 0.91 D, respectively, for the high CA/C group.

Conclusions. Visual performance in night myopia can be optimized by taking into account intersubject differences in dark focus and CA/C ratio. Best visual performance was found with a lens roughly equaling the full dark focus for subjects with low CA/C ratios and half the dark focus for subjects with high CA/C ratios. Invest Ophthalmol Vis Sci. 1995;36:1573–1580.

Night myopia is the condition in which the refractive power of the eye increases at low luminance.[1-5] Accommodation in excess of the viewing distance,[4,6,7] as well as spherical[2,8,9] and chromatic[9-11] aberration, are chiefly responsible for this effect. The main thrust of recent research on night myopia has been its accommodative component, which has led to the proposal that night myopia is a specific manifestation of the general tendency of accommodation to seek its resting position or dark focus under degraded stimulus conditions.[12] The primary evidence for this idea is the close correlation between the dark focus, which varies widely among subjects, and the level of accommodation at low luminance.[13-16] Based on similar evidence, instrument myopia[17,18] and empty-field myopia[19] also are thought to result from the regression of accommodation to its resting state.

Although it is generally accepted that neutralization of the excess refractive power that is associated with night myopia should lead to improved visual performance, an effective method for prescribing the optimal lens has eluded investigators.[5,20-22] One difficulty is that the tendency of accommodation to default to its resting point, which is complete in total darkness,[23] often is incomplete under low light levels. For example, if there is enough luminance to sustain binocular fusion, accommodation is influenced by fusional vergence.[21-24] The degree to which fusional vergence influences accommodation is known as the convergence accommodation to convergence (CA/C) ratio.[25-27] This terminology, although widely used, is misleading because it fails to convey the bidirectional effect of fusional vergence on accommodation—that is, divergence leads to less accommodation as much as convergence leads to more. For example, if the object of regard is far away, the eyes are relatively diverged and the effect of fusional vergence should be to de-

crease night myopia.[21,22,24] However, the actual degree of night myopia under such circumstances would depend on the CA/C ratio, which, like the dark focus, varies considerably among subjects.[21,22]

Thus, the crux of establishing the optimal optical compensation for night myopia seems to lie in understanding how the dark focus and CA/C ratio interact to determine the level of accommodation at low luminance. However, until the current study, no investigation has been so directed. Our goal was to perform a laboratory experiment in which the subjects viewed binocularly with natural pupils that would relate the power of the best optical compensation to individual differences in the dark focus and CA/C ratio.

METHODS

The best correction for night myopia was determined by measuring visual acuity (VA) and contrast sensitivity (CS) under binocular conditions across three luminances (0.04, 0.4, and 4.0 cd/m^2) and four lens powers (0.0, -0.5, -1.0, and -1.5 diopters [D]) using a 3 $\times$ 4 block design. Stimulus presentation was counterbalanced for lens power at each luminance, and the luminances were presented in ascending order to save adaptation time and to discourage learning effects. The subjects were dark adapted for 10 minutes before data collection. In addition, the dark focus and the CA/C ratio were measured for each subject, as was the level of accommodation with the 0.0 D lens across the full range of luminances.

Visual acuity and CS were determined psychophysically with computer-generated letter charts displayed on a high-resolution video monitor.[28] The design principles and scoring methodology for the charts were described elsewhere.[29,30] For VA, contrast was 93%, and Snellen letter size varied from 20/16 to 20/126 in 0.1 log unit steps. For CS, letter size was constant, but contrast varied from 93% to 5% in 0.1 log unit steps. A different letter size was used for CS at each luminance (20/126 at 0.04 cd/m^2, 20/64 at 0.4 cd/m^2, and 20/32 at 4.0 cd/m^2), such that CS always was measured with a letter size slightly larger than the VA threshold. This approach ensured that CS would provide a sensitive index of optical defocus.[28]

Accommodation was measured under binocular conditions with a dynamic infrared optometer[31] that was integrated into a binocular, dual Purkinje image infrared eyetracker.[32] The integration of the two enabled us to make continuous, precise (± 0.1 D), and objective measurements of accommodation that were unaffected by small horizontal and vertical eye movements. The video monitor was viewed through a pair of optical systems, one for each eye, known as stimulus deflectors.[33] The latter, which were designed for compatibility with the optometer and eyetracker, were used to control the optical characteristics of the stimulus, its luminance (with neutral density filters), and to image artificial pupils. The distance between the monitor and the stimulus deflectors was 2.7 m; however, the stimulus deflectors were adjusted so that the emergent optical vergence was 0.0 D and there was no vertical or horizontal prism. Auxiliary lenses were used to obtain the desired overcorrection.

Accommodation and vergence were measured continuously for 15 seconds/trial. The analog optometer and eyetracker outputs were digitized at a rate of 20 samples/second, and the mean of the 300 samples was used to represent accommodation and vergence for that trial. CA/C ratio was determined by opening the accommodative feedback loop by imaging a 0.75-mm diameter artificial pupil into the entrance pupil of each eye and stimulating fusional vergence by changing vergence demand from 0 to 6 prism diopters base out. The subsequent changes in vergence and accommodation were measured, and the change in accommodation was divided by the change in vergence.

Because the optometer required the use of dilating eyedrops, which conflicted with our desire to have natural pupils, we performed the experiment in two stages. In the first stage, pupil size was measured at each light level without mydriasis using an infrared video camera and a monitor. In the second stage, the psychophysical and oculomotor data were recorded after the pupils were dilated with 2.5% phenylephrine. However, artificial pupils were used that matched the natural pupil size measured in stage one. The use of phenylephrine, although the accepted practice for some types of infrared optometers,[18,23,27,31,34,35] may have contributed to variability in the accommodative data because phenylephrine can have an effect on accommodation that is both subject specific and time varying.[36]

The research followed the tenets of the Declaration of Helsinki. Informed consent was obtained after the nature and possible consequences of the study were explained. The research was approved by the Scientific Review Committee and the Human Use Committee of the US Army Aeromedical Research Laboratory. Sixteen subjects were recruited for the experiment. The mean $\pm$ SD age was 25.4 $\pm$ 3.0 years. All subjects had unaided visual acuities of at least 20/20 in each eye and did not have eye disease or other ocular anomalies.

Unless otherwise indicated, statistical analysis was by analysis of variance. For within-subject factors, the degrees of freedom were corrected using the Greenhouse–Geisser method when the assumption of sphericity was violated.[37]
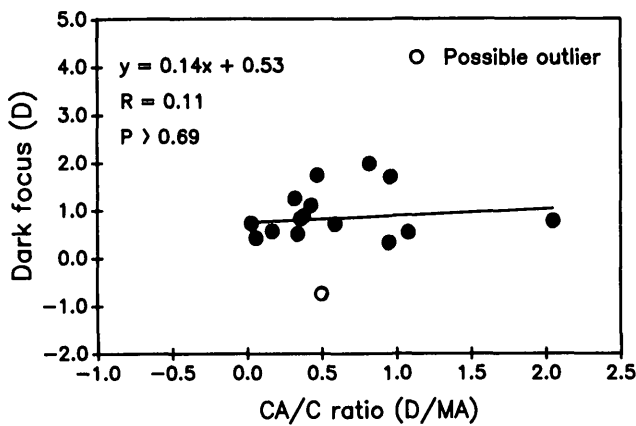
FIGURE 1. Dark focus as a function of CA/C ratio. The open circle indicates an apparent outlier. The statistics listed on the graph include the outlier. Without the outlier, the relationship is still not significant ($R = 0.10$, $P > 0.73$).

RESULTS

Oculomotor Responses

Mean ± SD dark focus and CA/C ratio were 0.84 ± 0.65 D and 0.59 ± 0.50 D/MA, respectively. Dark focus means reported in the literature generally have ranged between 0 and 2 D. Although there are exceptions, means less than 1 D are more common with infrared optometers (such as the one used in the present investigation),[18,38-41] whereas means greater than 1 D are more common with laser optometers.[12,42,43] CA/C ratio means reported in the literature have ranged from 0.30 to 0.93 D/MA.[25,26,34,35,44-46]

When tested with simple linear regression, dark focus was found to be unrelated to CA/C ratio (Fig. 1). However, accommodation (without an overcorrection) was significantly correlated with dark focus at each level of luminance but not with CA/C ratio (Table 1). Furthermore, when dark focus and CA/C ratio were used as independent variables in multiple linear regression, only dark focus successfully predicted accommodation, regardless of level of luminance—that is, CA/C ratio played no statistically significant role in explaining the variance of accommodation either alone or in combination with dark focus. The latter can be appreciated better by inspecting Table 2, which shows that the accommodative variance explained (represented by R^2) did not change significantly when CA/C ratio was added to the multiple regression.

Although accommodation was not directly related to CA/C ratio, we found evidence of an indirect relationship. In Figure 2, the subjects were divided equally into low and high CA/C groups; those with the eight lowest ratios were assigned to the low group, and those with the eight highest ratios were assigned to the high group. Accommodation was measured separately for the VA and CS charts. Because no difference in accom-

modation to the two types of targets was evident, the accommodative responses to VA and CS charts were averaged. It can be seen that accommodation at low luminance was related to dark focus under binocular conditions, consistent with other studies.[18,24] However, the slope of the regression line relating accommodation to dark focus was steeper for the low CA/C group by nearly a factor of 2. Similar relations between accommodation and dark focus were found at the other luminances.

The mean level of accommodation for low, medium, and high luminance was 0.78, 0.68, and 0.77 D, respectively. These means did not differ significantly ($F_{1.92,26.88} = 2.08$, $P > 0.12$, $MS = 0.050$), and there was no significant interaction between luminance and CA/C ratio ($F_{1.92,26.88} = 0.09$, $P > 0.90$, $MS = 0.002$).

Visual Performance

Figure 3 shows that visual performance improved over the 0.0 D baseline with minus-lens overcorrections, of which the −0.5 D lens typically was the best. However, this is misleading because visual performance actually declined with the −0.5 D lens for several subjects compared to the 0.0 D control.

Optimal Lens

We define the optimal lens as the one from among the four used in the experiment that provided the best visual performance for each subject on an individual basis. In most cases, the lens that optimized VA also was the one that optimized CS. However, when a conflict occurred, the optimal lens was obtained by averaging the power of the best lens for VA with that of the best lens for CS.

Figure 4 shows the degree of improvement in visual performance with the optimal lens (open bars) over the control condition (0.0 D lens). Also depicted is the degree of improvement in visual performance

TABLE 1. Simple Linear Regression of Accomodation on Dark Focus and Convergence Accommodation to Convergence Ratio at Three Levels of Luminance

Luminance (cd/m²)	Dark Focus		Convergence Accommodation to Convergence Ratio	
	R	P<	R	P>
0.04	0.916	0.001*	0.104	0.60
0.4	0.897	0.001*	0.085	0.75
4.0	0.935	0.001*	0.119	0.66

* Significant.

TABLE 2. Multiple Linear Regression of Accommodation on Dark Focus and Convergence Accommodation to Convergence Ratio at Three Levels of Luminance

Luminance (cd/m²)	R^2 (dark focus)	R^2 (dark focus + Convergence Accommodation to Convergence ratio)	Change in R^2 (from Convergence Accommodation to Convergence ratio)
0.04	0.8386*	0.8405	0.0019
0.4	0.8045*	0.8046	0.0001
4.0	0.8747*	0.8751	0.0004

* Significant.

over the control condition that would have resulted if a −0.5 D overcorrection (cross-hatched bars) were given to all subjects. The latter is the best one-for-all lens for our sample from the four lenses tested. The optimal lens was significantly better than control under all conditions, whereas the best one-for-all lens was no different than the control under four of the six conditions (Table 3). The average improvement in visual performance for the optimal lens was 0.14 log units (38%) compared to 0.08 log units (20%) for the best one-for-all lens, a difference of nearly a factor of 2. Furthermore, it is likely that the best one-for-all lens would vary from sample to sample because the factors that underlie it, namely dark focus and CA/C ratio, are themselves subject to considerable intersample variability.[18,25,26,34,35,38-46] This would seem to justify the admonitions of several investigators against prescribing an arbitrary overcorrection.[5,16,19]
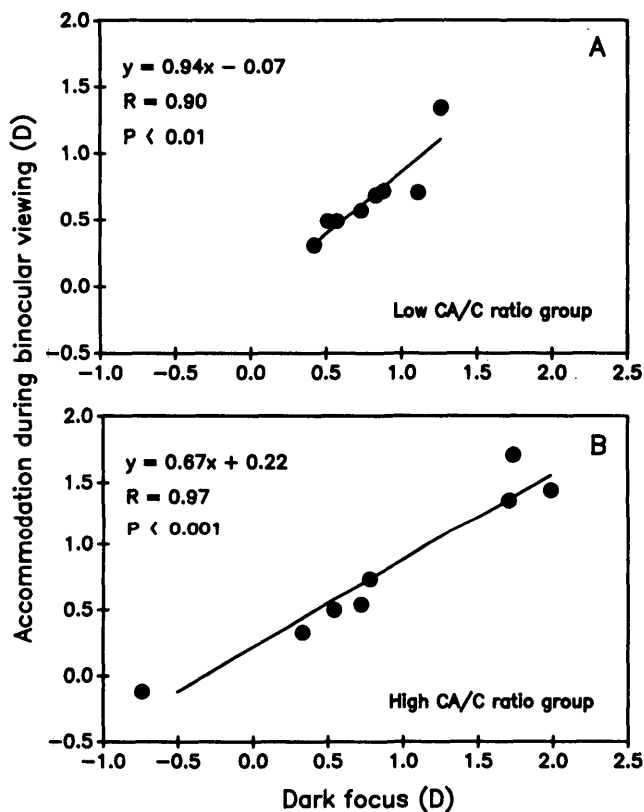
Figure 5 illustrates the relationship between opti-

FIGURE 2. Accommodation during binocular viewing as a function of dark focus. Luminance was 0.04 cd/m², accommodative demand was 0.0 D, and vergence demand was 0.0 MA. Artificial pupils were used that matched the natural pupil size for each subject. The subjects were divided equally into low and high CA/C ratio groups. (A) Low CA/C ratio group. (B) High CA/C ratio group.
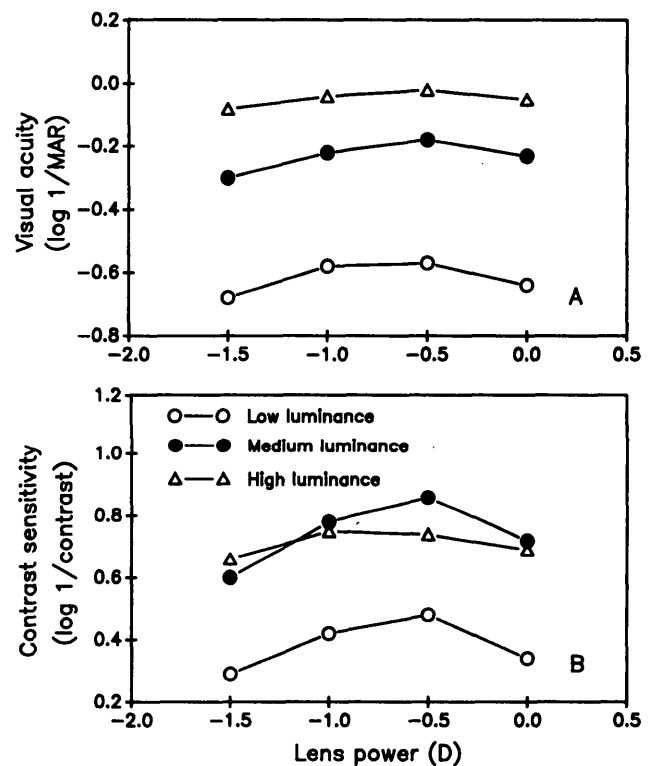

FIGURE 3. Effects of luminance level and minus-lens overcorrection power on visual performance. Each data point represents the mean for all subjects. All means are within-subject means; therefore, there are no error bars. A and B have equivalent units and ranges on the ordinate to facilitate comparison. (A) Visual acuity. (B) Contrast sensitivity.
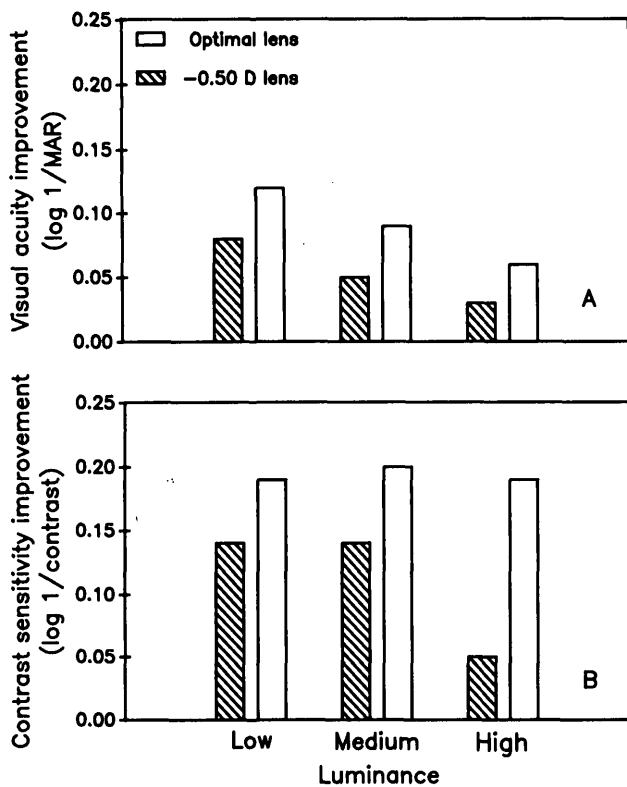
FIGURE 4. Improvement in visual performance from minus-lens overcorrections compared to the control condition (0.0 D lens). All means are within-subject means; therefore, there are no error bars. A and B have equivalent units and ranges on the ordinate to facilitate comparison. (A) Visual acuity. (B) Contrast sensitivity.

mal lens power, dark focus, and CA/C ratio. The subjects were placed in low ($n = 7$) and high ($n = 9$) CA/C ratio groups depending on whether their individual CA/C ratios were lower or higher than 0.4 D/MA. This cutoff, which was selected on a trial-and-error basis, seemed to demarcate CA/C ratios that greatly limited the regression of accommodation to the dark focus from those that did not. It is evident from Figure 5 that optimal lens power is related to the dark focus for both groups. The slope was steeper for the low CA/C group by analysis of variance of regression coefficients ($F_{2,12} = 36.44$, $P = 0.00001$, $MS = 0.790$). This suggests that the optimal lens is considerably stronger for a person with a low CA/C ratio than for a person with a high CA/C ratio, given equal dark focuses.

In Figure 6, we address the question of whether improvement in VA (Fig. 6A) and CS (Fig. 6B) with the optimal lens is a function of both dark focus and CA/C ratio. The subjects were divided into low and high CA/C ratio groups as in Figure 5 (filled and open circles, respectively). The improvement in both VA and CS did vary with dark focus by simple linear regression when all subjects from both CA/C groups were included in the analysis ($P < 0.03$ for VA and P

< 0.005 for CS); however, the improvement in visual performance was not statistically different between the CA/C groups for either visual function by analysis of variance of regression coefficients ($F_{2,12} = 0.08$, $P > 0.92$, $MS = 0.001$ for VA; and $F_{2,12} = 0.40$, $P > 0.67$, $MS = 0.006$ for CS). Thus, improvement in visual performance with the optimal lens was a function of dark focus but not of CA/C ratio. The lack of an effect for CA/C ratio probably was caused by compensation by the optimal lens for between-group differences in CA/C ratio, which may have afforded both groups a similar opportunity for improved vision (the optimal lens was based on a greater proportion of dark focus for the low CA/C group than for the high).

DISCUSSION

We found that, even in the presence of binocular fusion and regardless of CA/C ratio, the power of the optimal lens for night myopia is strongly related to dark focus. This conclusion is supported by accommodative data taken under reduced illumination (Table 1 and Fig. 2) and is consistent with previous studies in which accommodation during binocular viewing was found to be correlated with dark focus.[18,24] More important, we discovered that the influence of dark focus on the ideal prescription, given by the slope of the regression line relating lens power to dark focus (e.g., Fig. 5), varies according to CA/C ratio. The magnitude of the best optical overcorrection seems to be roughly that of the dark focus for individuals with low CA/C ratios (Fig. 5A) and approximately half that of the dark focus for individuals with high CA/C ratios (Fig. 5B). This rule of thumb breaks down a little for

TABLE 3. Improvement in Visual Performance in Log Units Over the Control Condition (O.O D) With the Optimal Lens and the Best One-for-All Lens (−0.5 D)

Luminance (cd/m²)	Visual Acuity		Contrast Sensitivity	
	Increase	P	Increase	P
Optimal lens				
0.04	0.12	<0.003*	0.19	<0.0004*
0.4	0.09	<0.001*	0.20	<0.001*
4.0	0.07	<0.006*	0.19	<0.02*
−0.5 D lens				
0.04	0.08	>0.05	0.14	<0.007*
0.4	0.05	>0.31	0.14	<0.04*
4.0	0.04	>0.10	0.05	>0.89

Multiple comparisons were performed with paired *t*-tests, and *P* values were adjusted for alpha inflation using the Bonferroni method.
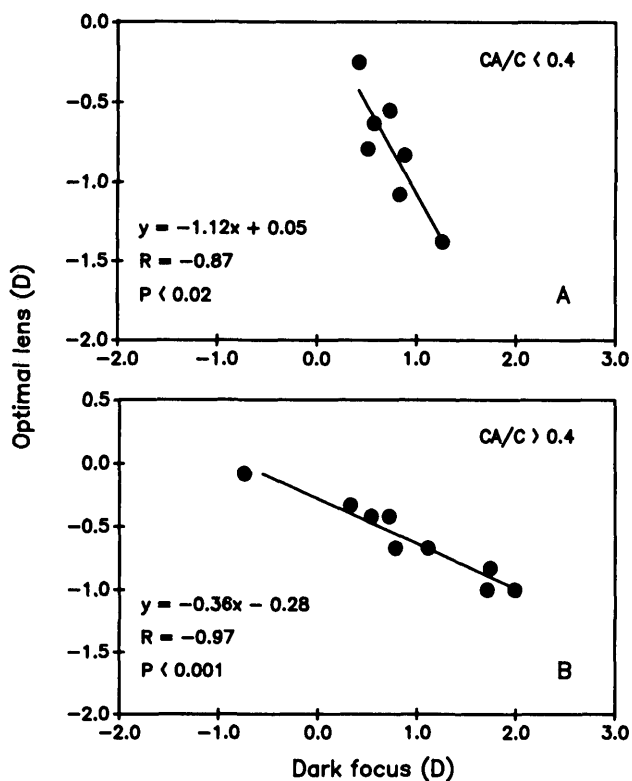* Significant.

FIGURE 5. Effects of dark focus and CA/C ratio on optimal lens power. (A) Plot of data from seven subjects with CA/C ratios lower than 0.4 D/MA. (B) Plot of data from nine subjects with CA/C ratios greater than 0.4 D/MA.

the high CA/C group when the dark focus is 0.5 D or less, in which case the best lens seems closer to the full dark focus.

The interrelationship described above between dark focus and CA/C ratio is consistent with predictions made by Leibowitz et al.[21,22] However, the Leibowitz group has already tested a night myopia lens that equaled half the dark focus and found this lens did not improve visual performance under conditions similar to those of the present experiment.[21,22] This apparent discrepancy may be the result of overestimation of accommodation by the laser optometer. In fact, Leibowitz et al[21,22] found evidence consistent with this hypothesis, as have several other investigators.[38,47-49]

Probably the major unresolved issue in the current study was the absence of an effect for luminance, given that neither accommodation nor optimal lens power varied significantly from 0.04 to 4.0 cd/m^2. The issue here is not so much whether luminance affects accommodation, and hence night myopia, because the linkage between accommodation and luminance has been well established.[14,18,50] Rather, the issue is what factors in our experiment dampened the effect of luminance on accommodation and whether these factors operate in the real world as well as in the laboratory.

One factor that may have contributed to the ab-

sence of a luminance effect was the relative proximity between the dioptric stimulus and the dark focus. It has been shown that when the stimulus to accommodation is placed at the dark focus, accommodation does not change with luminance.[51] In addition, the increased variability of accommodation known to occur under low light levels[52] could have masked changes in accommodation due to luminance by superimposing accommodative fluctuation due to random chance. Also, it is possible that there was an interaction between instrument myopia and night myopia in our experiments, because the subjects viewed the targets through an optical device. More work is needed to delineate the role of luminance in determining the optimal optical correction for night myopia.

Other issues that require additional research include the long-term effects of the optimal lens, whether optimal lens power varies with age, and whether an optimal lens prescribed in a laboratory or clinical setting is effective in a field environment. Although several investigators have demonstrated that commercially available autorefractors can be used to measure dark focus,[14,23,27,38,40,47,48] and clinical methods for measuring the CA/C ratio have been
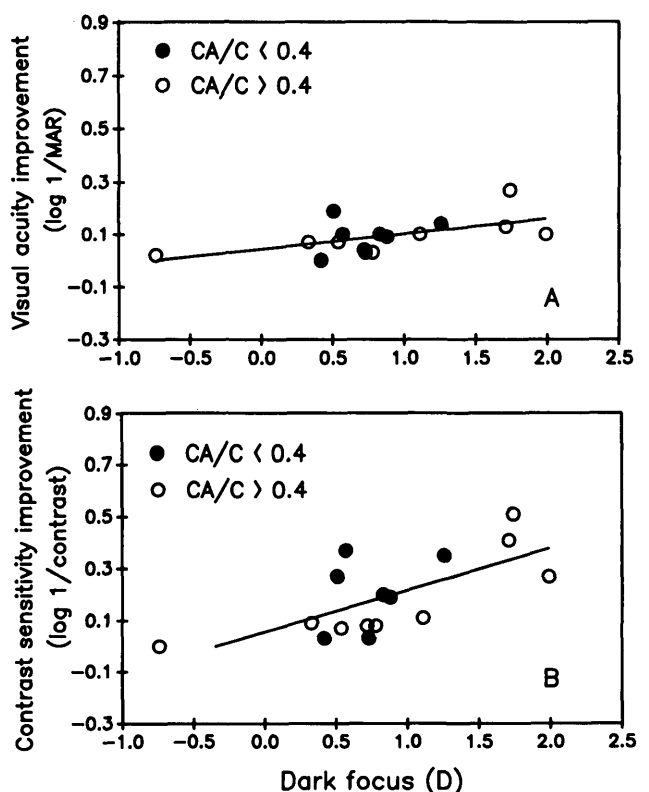

FIGURE 6. Effects of dark focus on improvement in visual performance with the optimal lens. Subjects were divided into low and high CA/C groups, and the dependent variable was averaged across luminance, in the same manner as in Figure 4. (A) Visual acuity. (B) Contrast sensitivity.

tested,[34,35,46] the measurement of dark focus and CA/C ratio in a clinical setting is still fairly novel. We suggest that clinical research be conducted to resolve the remaining issues before individual clinicians go about prescribing for night myopia based on our findings.

We close with a speculation concerning the apparent difference in dark focus distributions between our low and high CA/C groups. It can be seen from Figures 2, 5, and 6 that the dark focus range seems to be narrower for the low CA/C group, and, in fact, the difference in variance between the two samples is statistically significant ($P < 0.05$ by the Levene test for variability). The association of the more limited dark focus range with low CA/C ratios has an advantage because individuals with low CA/C ratios are poorly equipped to prevent extreme values of dark focus from expressing themselves as extreme values of night myopia. This is because, unlike their counterparts with high CA/C ratios, the accommodation of persons with low CA/C ratios is relatively unrestrained by fusional vergence under low light levels. Because different "night emmetropization" mechanisms apparently exist for both CA/C groups, one would expect that extreme values of night myopia are somewhat rare in the general population, and this appears to be so.[5,9,20,49] For example, a prevalence of <5% of night myopia greater than or equal to 1.75 D was reported in a recent large-sample study ($n = 380$).[49]

Key Words

accommodation, CA/C ratio, dark focus, night myopia, optical correction

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