Lateral Phoria at Distance: Contributions of Accommodation

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Lateral heterophoria at distance often is cited as an index of tonic vergence, yet recent research has shown that vergence in darkness is more convergent than most measures of phoria. Two experiments were conducted to investigate the possible role of accommodation in this discrepancy. Experiment I compared measures of distance phoria of 19 young adults with measures of vergence and accommodation of the same subjects. Dark vergence was found to be correlated with but significantly more convergent than distance phoria. Hierarchical regression analysis showed that individual measures of phoria were related to subjects' negative accommodation (from the dark focus to the distant target) as well as to dark vergence. Experiment II tested 13 young adults to evaluate three simple models of the influence of accommodation on distance phoria. Distance phoria was predicted best by a model that included the subjects' negative accommodation, accommodative vergence, and dark vergence. These findings support the hypothesis that distance phoria is influenced by accommodation for the fixation target. Dark vergence is a simpler index of tonic vergence.

Historically, phoria has been used as the standard clinical measure of extraocular muscle balance, and lateral phoria has been generally accepted as an index of the resting or tonic posture of binocular vergence.† Contemporary research on tonic vergence, however, has revealed a puzzling discrepancy.§ Measurements of binocular alignment in total darkness (dark vergence), where there is no visual stimulus for vergence or accommodation, typically show a more convergent posture than those obtained with measures of distance phoria. Francis and Owens,¶ for example, found the average dark vergence of 17 subjects to be 3.78° of convergence, a value significantly higher than the average distance phoria (1.44°) of the same subjects. They also found the measures of dark vergence and distance lateral phoria were only weakly correlated (r = 0.40; P > 0.05). This finding, which has been reported by several laboratories,‖ suggests that lateral phoria and dark vergence measures are assessing different processes.

The presumption that distance lateral phoria represents the resting state of the vergence system is grounded on theories of vergence and accommodation formed in the late 19th century. According to classical theory, vergence posture depends largely on three sources of innervation: tonic, accommodative, and fusional (reflex). A fourth source of innervation, called proximal vergence, was considered to be less important and perhaps less tractable experimentally because it depends on "knowledge of nearness" or voluntary convergence effort. All four components of vergence control were assumed to combine additively. Moreover, active vergence responses were thought to be unidirectional, acting only to converge the eyes, whereas divergent movements were attributed to passive mechanical forces. The basic, anatomical resting position of divergence was obscured by tonic convergent innervation in alert subjects. Later research showed that, similar to skeletal movements, vergence eye movements involve opponent muscles groups that act to diverge as well as to converge the eyes.¶ Thus, current theory holds that the physiologic resting state represents the balance of opposing divergent and convergent tonic activity.

Another important assumption of the traditional approach maintains that ocular accommodation relaxes at the far point of its operating range. This implies that accommodative activity and, therefore, accommodative-convergence can be eliminated by distant fixation. According to this traditional theory, a distant monocular stimulus should not stimulate vergence through fusional or accommodative mechanisms. Proximal effects, such as "knowledge of nearness," also are presumably avoided with distant fixa-
tion. Therefore, by subtraction, the only remaining innervation component would be tonic convergence. Although determining the absolute level of tonic innervation also would require knowledge of the anatomic resting position, which is rarely available, lateral phoria at distance has been taken as a useful approximation of tonic vergence relative to the presumed ideal of parallel visual axes.

Contemporary research on accommodation suggests that the discrepancy between measures of dark vergence and distance phoria may arise from a misconception about the resting state of accommodation. Contrary to the assumption that accommodation relaxes at infinity, measures of accommodation in the absence of stimulation have established that, for most individuals, the resting focus corresponds to an intermediate distance. Similar to the current conception of vergence control, these findings support an alternate theory of accommodation, which maintains that the resting focus corresponds to an intermediate distance and that active effort is exerted to adjust to distant and to near stimuli (Weber, 1855). According to this view, a monocular stimulus that is farther than the resting focus will elicit a negative accommodation response, and this negative response would be accompanied by accommodative divergent.

From this perspective, vergence posture when viewing a distant monocular target would be expected to differ from that found in complete darkness, because the fixation target will stimulate accommodative divergence. Thus, conventional measures of lateral phoria at distance would be predicted to depend on the subject's accommodation and tonic vergence. According to the intermediate-resting-state theory, the magnitude of the negative accommodation response depends on the subject's characteristic resting focus. Individuals who have a near resting focus should exhibit a relatively large negative accommodation response and, consequently, should yield phoria measures that include a larger accommodative component than subjects who have a distant resting focus. This analysis suggests, for example, a possible relationship between refractive error and lateral heterophoria. Several studies have reported that corrected hyperopes tend to exhibit higher levels of tonic accommodation than corrected myopes. Thus, corrected hyperopes would be expected to exert greater negative accommodation for a distant fixation target. This negative accommodation would be expected to induce accommodative divergence, creating a larger discrepancy between dark vergence and phoria than that found in myopes.

The important point is, according to our current understanding of vergence and accommodation, distance phoria cannot be assumed to reflect tonic vergence independent of accommodation. Rather, it is also likely to be contaminated by accommodative divergence.

The present study reports two experiments that investigated this hypothesis by comparing measures of lateral heterophoria to laboratory measures of vergence and accommodation, both in darkness (ie, the dark vergence and dark focus postures), and when viewing monocular accommodative stimuli similar to the fixation stimuli used in phoria tests. Experiment I was an exploratory study that used hierarchical regression analyses to determine whether lateral phoria is influenced by accommodative activity as well as tonic vergence. Experiment II extended the first study to evaluate three simple models of the contributions of tonic vergence, accommodative activity, and accommodative vergence.

**Experiment I**

**Materials and Methods**

*Subjects:* Nineteen subjects, ranging in age from 18 to 36 yr (mean = 19.8 yr) were tested. Seventeen (10 female and seven male) were students who received credit in an introductory psychology course for participating and who were naive regarding the purpose of the experiment. The authors also served as subjects. All subjects wore their normal corrections throughout the experiment. Distance binocular acuity scores, measured with a Bausch & Lomb (Rochester, NY) Master Orthorater, were 20/18 or better for 13 of the subjects; 20/20 for three; 20/22 for one; and 20/33 for two. (One of those who scored 20/33 reported that he had just finished taking an hour-long exam.) None of the subjects wore spectacle corrections, although some wore contact lenses.

**Apparatus:** Vergence and accommodation were measured by subjective vernier alignment techniques: vergence with a Maddox rod and accommodation with a polarized vernier optometer.

Vergence was measured by flashing a bright point source for 100 msec at unpredictable intervals. The light point was viewed directly by the right eye, while a red Maddox rod intervened before the left eye. Thus, when the stimulus flashed, the left eye saw a vertical red streak and the right eye saw a bright white spot. The light-point stimulus was mounted on a track that extended 3.67 m in front of the subject. Its distance was varied until the subject reported that the white point and the red streak appeared to be superimposed. Measures of dark vergence and phoria were defined as the distance at which subjective alignment was achieved.

Accommodation of the right eye was measured with a polarized vernier optometer, which required...
subjects to judge the alignment of two adjoining vertical line segments that were flashed for 500 msec at unpredictable intervals. Orthogonally oriented polarizing filters were positioned so that they bisected a rear-illuminated vertical slit (1 × 60 mm) and the right and left halves of the subject’s right pupil. In accord with the Schiener principle, the vertical line segments appeared in alignment only when the slit was conjugate with the retina; otherwise the vertical line segments appeared offset laterally by an amount proportional to optical defocus. The left eye was occluded during all accommodative measurements. Similar to the vergence measurement technique, the stimulus was mounted on a track that extended 3.67 m along the line of sight of the subject’s right eye. Measures of accommodation were defined as the reciprocal of the distance at which the two line segments appeared subjectively aligned.

Accommodation and vergence each were measured under two conditions: (1) in complete darkness; and (2) with a distant (4 m) 3 × 3 monocular array of optotypes, each of which subtended a visual angle of 1.2°, had a background luminance of 857.2 cd/m², and a contrast (L_max − L_min/L_max + L_min) of 99.7%. This stimulus was visible only to the right eye through a first-surface mirror and a beam splitter.

The resting states, dark vergence and dark focus, were operationally defined as the mean of three measurements of vergence and accommodative postures measured in darkness. Lateral phoria and the accommodative response were defined as the reciprocal of the distance at which the subject fixated the distant monocular target.

Procedure: Testing was conducted in a large light-tight visual alley, 2.5 m wide and 12.8 m long. Upon entering the alley, subjects could observe the general dimensions of the room. During testing, each subject’s view was restricted to a monocular fixation stimulus at 4 m or darkness. It was considered unlikely, given the dimensions of the room, that either test condition would induce substantial levels of “proximal” vergence or accommodation.

All measurements of accommodation and vergence were obtained with a manual bracketing technique, which has been shown to provide measures comparable to staircase techniques. The order of the four dependent measures was counterbalanced across subjects. Prior to testing, informed consent was obtained from each subject after the experimental procedure was described fully.

Results

Table 1 presents descriptive statistics for all dependent variables, including lateral phoria, dark vergence, the accommodative response for the distant monocular target and dark focus. The magnitude of negative accommodation for the distant stimulus, defined as the difference between the subject’s dark focus and accommodation when viewing the phoria target, also is provided. All vergence measures are expressed in meter-angles (MA) to facilitate comparisons with accommodation.

A paired t-test revealed that the mean phoria was significantly less convergent than mean dark vergence (mean difference = 0.14 MA; t(18) = 2.77, P = 0.013). Accommodation for the monocular phoria target also was found to be significantly lower than the mean dark focus (mean difference = 0.42 D; t(18) = 3.83, P = 0.001).

A hierarchical regression analysis was conducted to explore the relationship of phoria to experimental measures of vergence and accommodation. In this technique, the independent variables are ordered according to their theoretical priority. Then, the extent to which each of these variables, added sequentially, contributes to predicting variation of the target variable is examined. At each level in the hierarchical regression analysis, an estimate (R²) of the proportion of variance in the target variable that can be accounted for by variation in the predictor variable or variables is obtained. An R² value equal to 1.0 indicates perfect prediction. The R² values are cumulative, so that R² indicates the portion of variance in the target variable accounted for by the first independent variable alone; R² indicates the total variance accounted for by the first and second independent variables in combination; and R² indicates the total variance accounted for by the first, second, and third independent variables in combination. Increments in the R² values at successive steps in the analysis represent the additional predictive power gained through the newly added independent variable. That is, R² (which equals R² − R²) specifies the portion of vari-

<table>
<thead>
<tr>
<th>Phoria</th>
<th>Dark vergence</th>
<th>Accommodation for phoria target</th>
<th>Dark focus</th>
<th>Negative accommodation</th>
</tr>
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<tbody>
<tr>
<td>0.79 MA ± 0.36</td>
<td>0.94 MA ± 0.37</td>
<td>1.00 D ± 0.64</td>
<td>1.42 D ± 0.65</td>
<td>0.42 D ± 0.48</td>
</tr>
</tbody>
</table>
ance of the target variable accounted for by the second predictor variable beyond that accounted for by the first predictor variable alone.

Table 2 provides a summary of the variance accounted for ($R^2$) and partial coefficients ($r$) at each stage of the hierarchical regression analysis. Because lateral phoria, the target variable, is theoretically linked to tonic vergence, and dark vergence is considered to be an alternate, potentially more accurate index of tonic vergence, dark vergence was taken as the first predictor variable. Based on the theoretical perspective outlined earlier, "negative accommodation," the difference in accommodation between the dark focus and the response for the monocular phoria stimulus, was taken as the second predictor variable. The individuals' absolute accommodative responses for the phoria stimulus and their dark focus values were included in the analysis as the third and fourth predictor variables.

To test whether assigning second-order causal priority to negative accommodation is appropriate, the absolute accommodative response for the phoria target and the dark focus were entered as the second predictor variable in separate analyses. The outcome confirmed that negative accommodation, which is the difference between these two variables, is a stronger predictor of lateral phoria than the absolute accommodative response or the dark focus alone.

The analysis showed that dark vergence accounted for nearly 67% of the variance in measures of lateral phoria ($R^2 = 0.667$; $F_{[1,17]} = 34.03$, $P < 0.001$). As illustrated in Figure 1, subjects who had relatively large (near) dark vergence values also tended to have greater esophoria. Consistent with previous findings, lateral phoria and dark vergence were not identical, however. The mean dark vergence was significantly greater than mean phoria, and approximately 33% of the variance in phoria is not related to dark vergence. This difference can be seen by comparing the solid regression line, which was fit to the data, to the dashed theoretical line, which indicates identity. The following stages of the hierarchical analysis examined the extent to which accommodative activity can account for the remaining variance.

When negative accommodation was added as the second predictor variable, an additional 8.5% of the variance in lateral phoria was accounted for ($R^2_{12} = 0.752$; $F_{[2,16]} = 24.28$, $P < 0.001$). This increase in $R^2$ was statistically significant ($R^2_{12} = 0.085$; $t_{[16]} = 2.35$, $P = 0.032$), and it was greater than that obtained when the absolute accommodative response for the phoria stimulus or the dark focus were used as the second predictor variable. Figure 2 illustrates the relationship between measures of lateral phoria and the predicted values of phoria based on negative accommodation as well as dark vergence. The predicted

Table 2. Outcome of hierarchical regression analysis of predictions of lateral phoria at distance, based on experimental measures of vergence and accommodation

<table>
<thead>
<tr>
<th>Predictor variables</th>
<th>$R^2$</th>
<th>$r$</th>
</tr>
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<tbody>
<tr>
<td>Dark vergence</td>
<td>0.667</td>
<td>0.817</td>
</tr>
<tr>
<td>Dark vergence and negative accommodation</td>
<td>0.752</td>
<td>0.867</td>
</tr>
<tr>
<td>Dark vergence, dark focus and accommodation</td>
<td>0.777</td>
<td>0.881</td>
</tr>
</tbody>
</table>

$R^2$ values indicate proportions of variance in lateral phoria accounted for by the indicated predictor variables; $r$ values indicate the corresponding regression coefficients.

Fig. 1. Scatter diagram illustrating the relationship between measures of dark vergence and distance lateral phoria of 19 young adults ($R^2 = 0.667$). The solid line represents the best linear fit to the data, while the dashed line indicates a slope of unity (identity for the two variables).

Fig. 2. Scatter diagram illustrating the relationship between distance lateral phoria and predictions based on each subject's negative accommodation and dark vergence values ($R^2 = 0.752$). The best linear fit to the data, indicated by the solid line, has a slope of unity.
values now more closely approximate the theoretical prediction of identity indicated. Unlike Figure 1, the obtained regression line is superimposed on the theoretical prediction.

Adding the dark focus or the absolute accommodative response as a third predictor variable did not improve the prediction. In both cases, the third predictor variable accounted for an additional 2.5% of the variance in lateral phoria ($R^2_{123} = 0.777$). This increase was not statistically significant ($R^2_{3.12} = 0.025; t[15] = 1.30, P = 0.215$).

Discussion

The results of Experiment I replicate previous reports that show measurements of lateral heterophoria, taken with a distant monocular stimulus, are significantly less convergent than dark vergence in the same subjects. Although the present results yielded a higher correlation between dark vergence and phoria than that reported by previous investigations, the present measures confirmed that dark vergence is more convergent than, and is not perfectly correlated with, lateral phoria at distance. The hierarchical regression analysis went a step farther by showing that the magnitude of negative accommodation accounts for a substantial and statistically significant portion of the residual variance in lateral phoria.

These findings support the hypothesis that lateral heterophoria depends on the subjects' accommodative activity as well as their tonic vergence. In general, individuals with low dark vergence levels and high negative accommodation tended to exhibit less convergent lateral phoria, whereas those with high dark vergence levels and low negative accommodation exhibit more convergent lateral phoria.

Experiment II sought to clarify the influence of accommodation on lateral phoria by also evaluating the strength of the synergistic input from accommodation to vergence control. Three simple models were evaluated on the basis of predictions generated from empirical measures. The models are summarized in Table 3.

Table 3. Three simple models of the contributions of vergence and accommodation to lateral heterophoria

<table>
<thead>
<tr>
<th>Model</th>
<th>Phoria formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Phoria = DV</td>
</tr>
<tr>
<td>B</td>
<td>Phoria = DV + AR(AC/A)</td>
</tr>
<tr>
<td>C</td>
<td>Phoria = DV + (AR - DF)(AC/A)</td>
</tr>
</tbody>
</table>

DV, dark vergence. DF, dark focus. AR, accommodative response. AC/A, accommodative-vergence/accommodation ratio.

Thus, phoria is represented as the sum of dark vergence and the magnitude of accommodative divergence, defined as the difference between the accommodative response and dark focus for the phoria stimulus, multiplied by the subject's AC/A ratio.

Experiment II

Materials and Methods

Subjects: Thirteen undergraduate students, ages 18 to 22 yr (mean = 19.7), were paid to serve in the experiment. Similar to Experiment 1, all subjects wore their normal corrections (only contact lenses) throughout the experiment. Distinct binocular acuity scores, measured with a wall chart at 6 m, were 20/15 or better for six, 20/20 for six, and 20/25 for one of the subjects.

Apparatus: Objective measures of accommodation were obtained with a Canon R-1 autorefractor (Canon USA, Lake Success, NY). A double-blind calibration test, which compared cycloplegic refractions of 26 eyes, showed that spherical equivalent refractive errors obtained with this instrument are highly correlated ($r = 0.99$) with static retinoscopy by an experienced optometrist. The R-1 requires only 200 msec for each measurement and provides a resolution of 0.12 D. An advantage of using the R-1 is that by measuring through a large beam splitter, the instrument affords the subject an open binocular view of near and far stimuli. All output from the R-1 was sent by a serial interface directly to a microcomputer for storage and analysis.

Vergence was assessed through subjective nonius alignment of dichoptically presented stimuli. Unlike Experiment 1, however, measures were obtained with an automated device, known as the "Vergamatic* (S. Spadafore, Lancaster, PA), which presents light-emitting diode (LED) stimuli under the control of a microprocessor. The stimulus array consists of two sets of LEDs, each covered by polarizing filters. One set is a vertical column of green LEDs that are ex-
posed selectively to the left eye; the other is a horizontal row of 128 yellow LEDs that are exposed singly to the right eye. During vergence measurement, subjects wore a pair of cross-polarized glasses, and Vergamatic the right eye. During vergence measurement, subjects were instructed to look at a green column of 128 yellow LEDs that are exposed singly to the right eye. The subject’s task was a forced choice registered by two response buttons, indicating to which side of the green column the lone yellow LED appeared. To minimize task-related biases of vergence, the interstimulus interval was unpredictable, varying randomly from 2 to 5 sec. Using the MOBS algorithm with a termination criterion of six reversals and a final step size no larger than 4% of the measurement range, each vergence measure typically required 8 to 12 stimulus presentations. For each trial, the subjective alignment determined by MOBS was converted to vergence posture in meter angles using the subject’s interpupillary distance, distance from the device to the subject, and the distance separating the green column and the final yellow LED.

The test environment and fixation targets for measures of distance phoria were the same as those used in Experiment I.

Procedure: Each subject participated in six randomly ordered conditions (3 stimulus configurations × 2 oculomotor measurements). The three stimulus configurations were: (1) complete darkness; (2) with the distant accommodative target visible to the right eye and; (3) with a near (25 cm) accommodative target visible to the right eye. In the latter two configurations, two techniques were employed to render the targets monocular. During accommodation measures, an occluder attached to the autorefractor was positioned over the subject’s left eye. For vergence measures, polarizing filters were attached to the fixation stimuli so they were visible only to the right eye. To maintain constant luminance, the polarizing filters were replaced by neutral density filters during accommodation measures.

Accommodative data were based on the mean of five measures of mean spherical refraction taken from the subject’s right eye, while vergence data, expressed as meter angles, were based on the mean of three measures with the Vergamatic. Response AC/A ratios were calculated as

\[
\text{AC/A ratio (ie, } 1.20 + (-0.60)(0.96) = 0.62 \text{ MA).}
\]

As in Experiment I, distance lateral phoria was defined as the mean vergence posture measured while the subject viewed the monocular stimulus at 4 m. Phoria measures also were obtained with a tabletop vision tester (B&L [Rochester, NY] Master Orthorater) and by von Graefe’s technique. These measures were not used in experimental analysis, however, because it was not possible to obtain objective measures of accommodation and response AC/A ratio under the relevant conditions. Prior to testing, informed consent was obtained from each subject after the experimental procedure was fully described.

Results

Table 4 presents mean data for lateral phoria, dark vergence, dark focus, accommodation for the phoria target, and response AC/A ratios. To expedite comparisons, all vergence and accommodation data are expressed in meter angles and diopters, respectively. Paired t-tests showed that the mean phoria was significantly less convergent than mean dark vergence (mean difference = 0.58 MA; t[12] = 6.35, P < 0.0001), a difference that is 0.44 MA greater than that found in Experiment I (Table 1). Mean accommodation for the monocular phoria target was significantly lower than the mean dark focus (mean difference = 0.61 D; t[12] = 2.80, P = 0.016), a difference that is 0.19 D greater than that found in Experiment I.

The three models were evaluated by comparing the predicted phoria values from each model with the measures of lateral phoria obtained for each of the subjects. Predicted phorias for each subject were obtained by inserting the empirical measures into the equations listed in Table 3.

Two statistical tests were used to assess the predictive power of the models. First, correlations were used

### Table 4. Mean (±SD) lateral phoria at distance and mean (±SD) experimental measures of vergence, accommodation, and response AC/A ratios of 13 young adults

<table>
<thead>
<tr>
<th>Phoria</th>
<th>Dark vergence</th>
<th>Accommodation for phoria target</th>
<th>Dark focus</th>
<th>Negative accommodation</th>
<th>AC/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral phoria</td>
<td>0.63 MA ± 0.39</td>
<td>1.20 MA ± 0.29</td>
<td>0.47 D ± 0.43</td>
<td>1.07 D ± 0.89</td>
<td>0.60 D ± 0.78</td>
</tr>
</tbody>
</table>

Note that, consistent with "Model C," mean phoria is closely predicted by

- AC/A ratios are defined as meter-angles/diopter.
- Note that, consistent with "Model C," mean phoria is closely predicted by

### Table 4

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to determine the extent to which the levels of phoria predicted by each model were related to the obtained measures of phoria for the same subjects. The obtained correlations are illustrated as scatter diagrams in Figure 3. It is evident that predictions from Model C, which included accommodative divergence as well as dark vergence components, yielded a correlation of 0.72 ($P < 0.005$) and accounted for 52.3% of the variance in obtained phoria. Model A, which assumed that distance phoria and dark vergence should be equivalent, yielded a correlation of 0.56 ($P < 0.05$) and accounted for 31.3% of the variance in phoria. Predictions from Model B, which adds an accommodative component based on the absolute accommodative response to the phoria stimulus multiplied by the subject’s AC/A ratio, showed the weakest relationship, yielding a nonsignificant correlation of 0.25 and accounting for only 6.25% of the variance in phoria measures. Comparison with Figure 1 shows that the correlation between dark vergence and lateral phoria here is lower ($r = 0.56$ vs. $r = 0.82$). Similar to Experiment 1, however, predictions of lateral phoria were enhanced by including negative accommodation—in this case, weighted by the subject’s AC/A ratio (Model C)—as well as dark vergence in the algorithm.

A low correlation indicates that the model’s predictions were not related to actual phoria, whereas a high correlation indicates a strong relationship. A high correlation does not assure that the model’s predictions are accurate, however. It is possible that the model predicts levels that are highly correlated with obtained values but that are consistently too high or too low. To evaluate the accuracy of the models, errors of prediction were computed for each model by finding the difference between the obtained and predicted levels of lateral phoria for each subject. Paired t-tests then were used to compare the prediction errors for the three models.

The mean errors of prediction are illustrated in Figure 4. Again, predictions from Model C were found to be superior, with a mean error of $-0.03$ MA, which is
not significantly different from zero ($t(12) = 0.16$, $P = 0.87$). Models A and B predicted phoria levels that were greater than obtained values. Both were significantly greater than zero, with the mean error of Model A 0.58 MA ($t(12) = 6.35$, $P < 0.00005$), and that of Model B 1.04 MA ($t(12) = 6.51$, $P < 0.00005$).

Discussion

The present results replicate and extend previous evidence that lateral heterophoria and dark vergence represent different vergence states. Although the two states are related, with empirical correlations ranging from around 0.3 to 0.8, dark vergence is consistently more convergent than lateral phoria at distance. Our findings confirm that this difference can be at least partly attributed to accommodative activity. Experiment I showed that a significant portion of the difference between dark vergence and distance phoria can be accounted for statistically by considering the subjects' negative accommodation* responses for the phoria target (Table 2). Individual differences in dark vergence accounted for 67% of the variance in distance phoria of the same subjects (Fig. 1). Including measures of negative accommodation in the regression analysis improved predictions significantly to account for 75% of the variance in phoria. At the same time, this addition eliminated differences in the mean magnitude of predicted and obtained phorias (Fig. 2). Experiment II extended these findings by showing that a simple model that includes the subjects' negative accommodation and AC/A ratio yields predictions that are more accurate (Fig. 4) and more strongly correlated (Fig. 3) with measured phoria than models that include no accommodation or the absolute level of accommodation without reference to the dark focus.

The variance in phoria accounted for by Model C (52.3%) is substantially lower than that accounted for in Experiment I by the combined predictor variables of dark vergence and negative accommodation (75.2%; Fig. 2). This discrepancy might be related to methodological differences. The procedure in Experiment II used an objective rather than a subjective measure of accommodation and a more rapid, bias-free method of assessing vergence. The difference also might reflect characteristics of the smaller sample of subjects used in Experiment II. In any event, we would emphasize that the primary discrepancy lies in the relationship between dark vergence and phoria (compare Figs. 1 and 3, Model A). The results from both experiments provide consistent support for the conclusion that negative accommodation influences lateral phoria at distance.

The Question of Generality: An anonymous reviewer raised an important and interesting question regarding the generality of our findings. Subjects in both of our experiments exhibited levels of esophoria and of accommodation for a distant target (4 m) that are high relative to frequently cited normative data. Are the data reported here representative of the general population? College students probably are not representative of the general population, but neither are they representative of a clinically abnormal population. Population norms can be misleading because they are not necessarily representative of all subgroups and they are not necessarily stable over time. Those derived from measures of farm workers or pilots are likely to differ from those of students or computer scientists, and those obtained several decades ago may deviate from the current population.

There is no indication that the present subjects were abnormal. The phoria levels of our subjects are comparable to those reported by other studies of students. The accommodation data also are typical. Many studies have shown that accommodative responses typically "lag" toward the dark focus and, therefore, tend to be somewhat "myopic." It is possible that a few of our subjects would have accepted a stronger myopic correction. However, if this were the case, the deviation from optimal correction would have been small. Only 4 of the 32 subjects exhibited distance acuities worse than 20/20; the two poorest acuities were 20/33. These measures indicate that clinically significant levels of uncorrected myopia were not characteristic of our subjects. Related to this issue, it is interesting to note that a recent longitudinal study of students revealed that refractive errors vary over the academic year, with increasing myopia during the winter months and decreasing myopia during the summer months. This may be related to the reluctance of many clinicians to prescribe small increments of minus refractive corrections to students. In summary, the present sample of subjects appears to represent the population of young adult students. Further research will be necessary to clarify the extent to which the student population shares or differs from characteristics of other occupational groups.

Individual differences are a fundamental characteristic of the normal population, and this variation may be very useful for understanding and predicting difficulties under challenging visual conditions. The pres-

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* The present discussion relies on a functional definition of "negative accommodation" as the class of focusing responses to stimuli farther than the resting posture. As shown by Gilmartin's analysis of tonic accommodation, one cannot assume that such responses are synonymous with sympathetic innervation to the ciliary muscle. Much remains to be learned about the physiologic mechanisms of accommodation and their linkage to binocular vergence.
ent findings are interesting in this context because they have a bearing on methods of assessing individual differences in tonic vergence. They indicate that standard measures of lateral heterophoria do not represent a simple measure of tonic vergence, but rather are likely to include an unspecified accommodative component. Moreover, these findings are derived from, and probably are most applicable to, an occupational group that is exposed to risk of difficulties with near tasks.46

Theoretical and practical implications: According to the present view, the difference between dark vergence and lateral phoria at distance can be attributed to accommodative divergence. In the absence of adequate stimulation, vergence and accommodation passively return to their respective resting (tonic) postures, which usually correspond to an intermediate distance.13,17 Introduction of an effective monocular target, such as an acuity chart, stimulates a negative accommodative response accompanied by accommodative divergence. Lateral phoria therefore is considered a problematic method for assessing tonic vergence because such measures are likely to be contaminated by accommodative activity.

An alternative interpretation, which adheres to the traditional assumption that accommodation and vergence rest at the far point, would account for the present findings differently. The assumption that accommodation for distance sends no cross-innervation to vergence requires the corollary that accommodation is active in darkness and, therefore, induces accommodative convergence. Thus, dark vergence would be said to deviate from distance phoria (the true tonic posture) because it includes an accommodative convergence component that arises from the dark focus.46 Although the present results indicate that accommodation is responsible for the difference between distance phoria and dark vergence, they do not rule decisively against this alternative interpretation. The terms presented in Model C (Table 3) can be rearranged to maintain that dark vergence is a function of lateral phoria plus dark accommodation multiplied by the AC/A ratio, ie, $DV = phoria + (DF - AR)(AC/A)$, without appreciable changes of the statistical analysis.

We reject this interpretation for several reasons. First, numerous investigations have shown that accommodation returns to the same intermediate posture that is found in darkness under a wide variety of viewing conditions, including bright empty fields, laser speckle patterns, optical instruments with adjustable focus, when viewing distant stimuli through pinhole pupils or through intervening surfaces like mesh screens,36,41-51 and when deliberately failing to attend to a fixated target.52 Other research has shown that adaptive changes of tonic accommodation occur with visual tasks that are nearer or farther than the dark focus distance, but they are not observed when the task corresponds to the dark focus distance.27,44,53 Physiologic and pharmacologic evidence indicates that the dark focus represents the combined activities of the sympathetic and parasympathetic branches of the autonomic nervous system.54 It would be extremely difficult to reconcile this growing empirical literature with the assumption that accommodation is inactive at the far point. Without that assumption, the alternative interpretation seems groundless.

Note that not all measures of phoria produce comparable results. In a clinical study of lateral phoria and tonic vergence, O’Shea et al21 showed that measures of lateral phoria are highly sensitive to the conditions of measurement. They found that measurements with von Graefe’s technique, which uses fixation of a monocular optotype, were less convergent than those obtained with the Maddox technique, which uses a fixation target that is less effective as an accommodative stimulus.53,56 Moreover, they found that lowering illumination of the examining room resulted in increased convergence (esophoria) with von Graefe’s technique. Similar to the present account, O’Shea et al argue that these variations in distance phoria can be attributed to accommodation, although they did not obtain empirical measures of accommodation to support this interpretation. This interpretation is reinforced by a recent report that lateral phoria at distance is not significantly different from measures of dark (tonic) vergence when the accommodation stimulus is “open-loop.”35

The present findings, and those of O’Shea et al,21 indicate that measures of lateral heterophoria at distance must be used with caution. In many instances, the phoria measure reflects accommodative as well as vergence activity. And the magnitude of accommodative involvement depends on at least four factors: (1) the quality of the fixation stimulus; (2) the subject’s characteristic dark focus (tonic accommodation); (3) the subject’s accommodation response gain, which can vary as a function of attentiveness52 as well as stimulus parameters and visual function;57 and (4) the subject’s AC/A ratio. These extraneous factors will confound assessments of tonic vergence.

In addition to clinical considerations, the distinction between dark vergence and lateral phoria has noteworthy practical consequences. A growing body of evidence indicates that individual differences in oculomotor tonus are associated with susceptibility to such problems as asthenopia and anomalous refractive errors.17,33,38,42,58 Several recent studies have found a relationship between dark vergence and visual discomfort from near work.32,44,59 Based on rat-
ings of visual discomfort, subjects with distant dark vergence postures generally experience greater symptoms than subjects with near dark vergence postures. Although some studies have reported a similar relationship between visual symptoms and lateral phoria, such findings have been variable and inconsistent. One recent study that measured both lateral phoria and dark vergence found a significant correlation between dark vergence and visual strain but no correlation between symptoms of near work and phoria. Although the mechanisms underlying visual discomfort are still obscure and are likely to be complex, the available evidence indicates that tonic vergence is an important factor. From the present perspective, conventional measures of lateral heterophoria are less fruitful in this regard because they are contaminated by accommodative divergence of variable magnitude.

Key words: lateral heterophoria, dark vergence, dark focus, negative accommodation

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