Investigative Ophthalmology & Visual Science, Vol. 32, No. 3, March 1991

Anisocoria

Variation and Clinical Observation With Different Conditions of Illumination and Accommodation

Ellen Richter Ettinger,* Harry J. Wyatt,* and Richard London†

Variations in anisocoria in light and dark conditions are used to help diagnose normal and pathologic conditions; however, there have been few observations of anisocoria in different lighting and accommodative conditions. The authors measured pupil size photographically in a group of normal subjects examined in six conditions that were controlled for illumination and accommodation. Greater variation and average extent of anisocoria were found in conditions that resulted in larger pupil size. A subset of subjects repeated several sessions. For this group, the average value of anisocoria and variability tended to be greater in dark conditions. These results show that the observation of anisocoria varies under different conditions, and they suggest careful consideration of conditions used clinically to assess pupil equality. Our analysis shows that for a given observation threshold, conditions that produce even modest changes in variability can cause dramatic changes in the probability of observing anisocoria. Invest Ophthalmol Vis Sci 32:501–509, 1991

The clinical finding of anisocoria is important in the differential diagnosis and proper management of various normal and pathologic conditions.[1–5] Given its importance, surprisingly little is known about the effect of various lighting and accommodative conditions on the equality of pupil size and the likelihood of correctly observing anisocoria under different conditions.

In the absence of any pathologic or abnormal conditions, anisocoria is usually referred to as "physiologic anisocoria" or "simple central anisocoria." This is fairly common in the normal population, with estimates typically ranging around 20%. Some variations in estimates are probably due to differences in observation techniques, experimental conditions, and differences in the criteria used for defining clinically observable anisocoria.[4–6]

Loewenfeld[4] considered a criterion of 0.4 mm or more as clinically significant; about 20% of her subjects under 60 yr of age showed anisocoria with this criterion. Using Loewenfeld's criterion, Lam and coworkers[6] found that about 19% of their subjects showed anisocoria at any particular time in the examination sequence, and 41% showed anisocoria at least once during a 5-day examination period. Of their subjects who showed anisocoria, most did not display it during every session. Anisocoria appears to be a variable phenomenon, but the range of this variability in normal and abnormal subjects, and under different conditions, has not been well documented.

We observed anisocoria in various conditions of illumination and accommodation in normal subjects. Our intent was to establish baselines for anisocoria under different conditions and to see if anisocoria varied systematically with condition. To examine intrasubject variability, some of our subjects repeated a series of identical sessions.

Materials and Methods

Subjects were positioned on a chin- and head-rest, facing into a matte-white hemisphere, uniformly illuminated (≤100 ft-lamberts). A 35-mm camera and a standard camera flash (covered with a red filter [No. 70 Wratten] to reduce the illumination of the flash) was used to minimize its function as a possible source of pupillary stimulation, while maintaining enough light for photography. The camera extended through a circular opening at the center of the hemisphere, and each subject was adjusted so that the subject's eye level was even with the axis of the camera lens.

Subjects, consisting of students, faculty members, and patients from the College of Optometry, were told of the purpose and procedures of the study, and

From the *State University of New York—State College of Optometry, New York, New York, and † Permanente Medical Group, Oakland, California.

Supported by Schnurmacher Institute for Vision Research of SUNY.

Submitted for publication: June 30, 1989; accepted June 14, 1990.

Reprint requests: Dr. Ellen Richter Ettinger, State University of New York—State College of Optometry, 100 East 24 Street, New York, NY 10010.

informed consent was obtained from all of them. All subjects had a complete eye examination including testing for refractive status, binocularity, and ocular health testing; no ocular pathology or amblyopia was present in any of the subjects. Participants ranged in age from 21–60 yr, and all were able to cooperate with the directions for the "near" and "far" conditions. No spectacle corrections or contact lenses were worn during the sessions.

Viewing was binocular, with natural pupils, and no pharmacologic agents were used. Subjects were instructed to look through the camera lens and into the distance for "far" conditions, and a small red fixation light could be turned on in the hemisphere adjacent to the camera (40 cm from the eye) when subjects were instructed to look at the near target ("near" conditions).

Six conditions were run in the sequence of light/dark and near/far combinations shown in Figure 1. To standardize stimulation for near and light responses across sessions, the conditions were run in the same order and time sequence, with photographs taken at the same times, for each subject. Four of the conditions (Light-1, Initial-Dark, Settled-Dark, and Light-2) were run as far conditions, and the remaining two conditions (Near-Dark and Near-Light) were run with instructions for near fixation.

The standardized protocol was as follows (Fig. 1). The subjects were seated and positioned at the hemisphere with the illumination turned on. For calibration, a ruler was taped to the forehead near the bridge of the nose. The subjects gazed into the distance and the timing was started; after 2 min, photograph 1 was taken ("Light-1"). Thirty seconds later, the hemisphere illumination was turned off, and 3 sec after that, photograph 2 was taken ("Initial-Dark"). One minute later, still in the dark, photograph 3 was taken ("Settled-Dark"). Thirty seconds later, the subjects were told to look at the red fixation light, and 3 sec after the instruction, photograph 4 was taken ("Near-Dark"). (The 3-sec interval allowed the subjects to fixate at near and for the near response of the pupil to stabilize.) Next the hemisphere illumination was turned back on, and the subjects were given instructions for the far condition again; after 2 min in the light, photograph 5 was taken ("Light-2"). Thirty seconds later, the subjects were told to look at the red fixation light, with the illumination still on, and after 3 sec, photograph 6 was taken ("Near-Light").

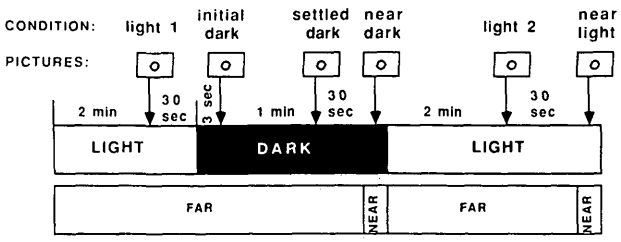


Fig. 1. The experimental protocol. Conditions consisted of a timed sequence of light/dark and near/far combinations. Photographs were taken at standard times during each session (indicated by ↓). See text for further details.

In some cases, a particular photograph could not be analyzed due to blinking. The two near conditions were initiated in the study after some subjects had been tested, so not all subjects were observed in these two conditions.

A group of 52 subjects was used, including six who were followed repeatedly to explore variability in each of the conditions over time. Subjects in the repeat group were run in identical sessions at widely spaced intervals (usually on different days), with at least five sessions each.

The developed film (Kodak Ektachrome EES 135; Rochester, NY) was projected at a magnification of 4×–4.5× onto a digitizing pad (Jandel Scientific, Corte Madera, CA) connected to a microcomputer. The outline of each pupil was traced, and a direct measurement of horizontal diameter was also made. A 2-cm length of the ruler attached to the subject's forehead was measured for calibration. From these measurements, we determined horizontal pupil diameter (direct measurement) and mean pupil diameter (computed from pupil area) for each pupil. (The area-derived measure will be reported.) Data from a single photograph consisted of average pupil diameter (average of left and right pupils), and anisocoria (right diameter minus left diameter).

Results

Measurement of Pupil Diameter and Anisocoria

For our entire set of measurements, we found that pupil diameters determined directly and those calculated from pupil area were highly correlated (correlation coefficient, 0.998). When anisocoria determined by the two techniques was compared (ie, the difference of the two directly measured diameters was compared with the difference of the two area-derived diameters), we found that the correlation was moderately strong, but there was more scatter (correlation coefficient, 0.719). In addition, the slope of the linear regression was 0.68; ie, the amount of anisocoria using area-derived diameters was somewhat smaller than the amount using directly measured diameters. An examination of some cases which deviated most from the correlation showed noncircular pupils (with different vertical and horizontal diameters) which were not symmetric between eyes; this was occasionally marked enough to give different signs of aniso-

coria derived from vertical versus horizontal diameters.

To evaluate variability of measurement (as distinct from actual pupil variability), a series of representative photographs were measured five times each. The distribution of average (of left and right) values of diameter determined from a single photograph had a typical standard deviation (SD) of 0.034 mm (range, 0.015–0.073 mm) for directly measured diameters and 0.032 mm (range, 0.016–0.040 mm) for area-derived diameters. The distribution of values of anisocoria determined from a single photograph had a typical SD of 0.092 mm (range, 0.065–0.134 mm) for directly measured diameters and 0.061 mm (range, 0.045 to 0.086 mm) for area-derived diameters. Overall, area-derived values were less subject to mea-

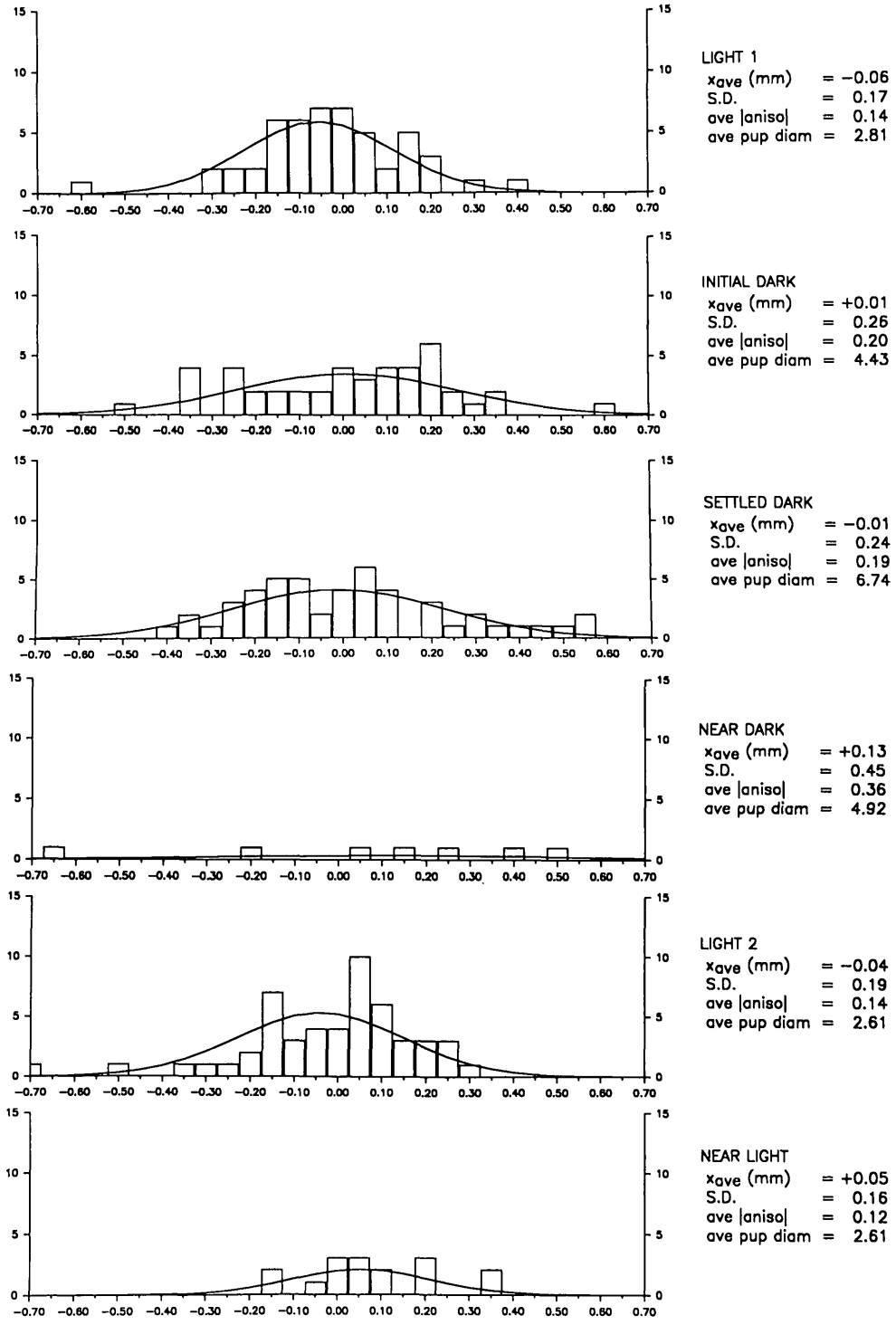


Fig. 2. Distributions of anisocoria observed in the population of subjects under the different conditions. X-axis: anisocoria in mm (positive values: right pupil larger than left), y-axis: number of subjects. Solid curves show normal distributions for the same total number of subjects, having the same mean and standard deviation as the data for each condition.

surement variability and were also unaffected by pupil-shape variations. We report area-derived values hereafter.

Results From the Full Set of Subjects

Figure 2 shows the distributions of anisocoria for each of the six conditions. Positive values of anisocoria indicate that the right pupil diameter was greater than the left. The measured diameters are grouped into 0.5-mm bins. Next to each histogram, the following information is provided for each condition: (1) "x_{ave} = the average of anisocoria across subjects; (2) SD = the standard deviation of the set, (3) "ave |aniso|," the average magnitude of anisocoria across subjects; and (4) the average pupil diameter across subjects. (The average anisocoria, x_{ave} the average of the signed value, keeps right/left information but loses information about the extent of anisocoria. The average magnitude, ave |aniso|, is the average of the absolute magnitude of anisocoria, which keeps information about extent but loses information about left/right.)

With each histogram, the normal distribution corresponding to the mean and standard deviation is plotted. These distributions are the best-fitting normal curves and represent the data well, as shown by the Kolmogorov-Smirnov test. (The hypothesis that the distribution from which the data were drawn was normal could not be rejected for any condition at a 0.1 confidence level.)

Anisocoria in Various Conditions

It is apparent from Figure 2 (and the SDs listed next to the distributions) that the normal distributions fit to the data were broader in the dark conditions (Settled-Dark and Near-Dark) than in the light conditions, suggesting that the anisocoria observed was more variable in dark conditions. The value of ave |aniso| was also greater in those conditions. The average value of anisocoria was not significantly different from zero in any condition.

To examine these trends, Figure 3 plots two measures of the distribution for each condition against the average pupil diameter for each condition; at the left, the SD, and at the right, the value of ave |aniso| is plotted against average pupil diameter. Both measures of variability of anisocoria increase with average pupil diameter. Although there was a positive correlation when all conditions were considered, the correlation was stronger if the Near-Dark condition was excluded from the set, since the distribution for that condition was strikingly broad. (We are not certain at this time whether the unusual breadth of the Near-Dark distribution will continue to appear when more subjects are tested. This condition was a late addition to the protocol, so there were fewer subjects examined (Fig. 2). Furthermore, one marked case of physiologic anisocoria was included in the small sample, which constituted a larger-than-usual fraction of the subjects. We therefore show the regressions of Figure 3 without the Near-Dark condition.) Without the Near-Dark point, the correlation coefficients for the remaining five points were 0.79 and 0.84 for the left and right plots, respectively. The linear regression for each plot (omitting the Near-Dark data) is included as a broken line.

To complement Figure 3, Figure 4 shows the individual values of |aniso| versus mean pupil diameter for all subjects and all conditions. The slope of the linear regression (broken line) is 0.023 which is similar to, but somewhat larger than, the slope of 0.017 in Figure 3 (right), calculated without the Near-Dark point. The unusually large values of anisocoria in the Near-Dark condition (filled squares) are apparent in this Figure. It should be remembered that Figure 4 is not intended to indicate a strong correlation between the magnitude of anisocoria and pupil diameter, but to indicate how the distribution of anisocoria varies under different conditions.

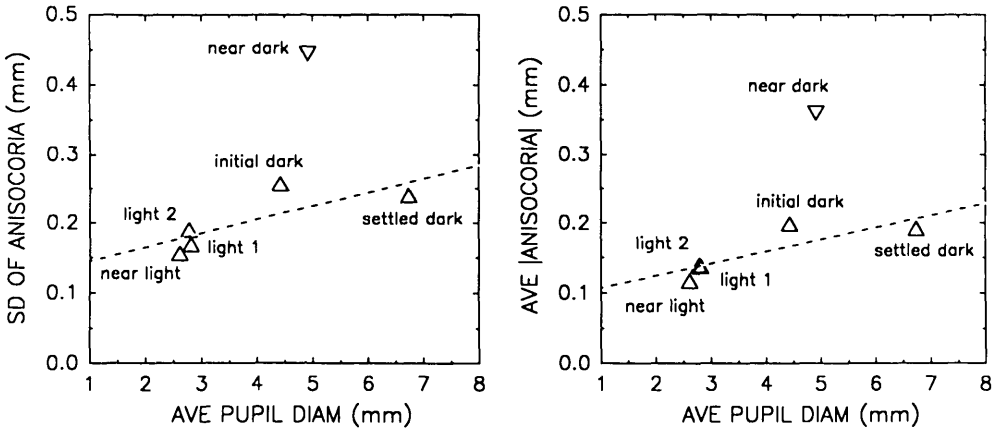


Fig. 3. Standard deviation of anisocoria distribution found in the population for each condition plotted against average pupil diameter for the same condition. Note the increase in distribution width for conditions producing large average pupil diameters.

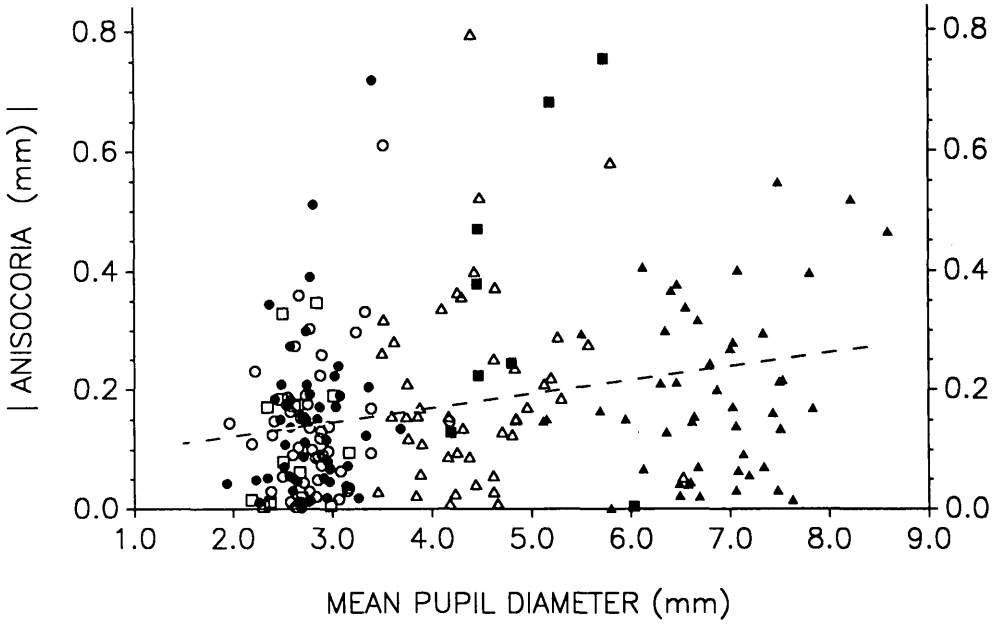


Fig. 4. Magnitude of anisocoria plotted against average pupil diameter for all subjects in the population in all conditions. Light-1: circles; Initial-Dark: triangles; Settled-Dark: filled triangles; Near-Dark: filled squares; Light-2: filled circles; Near-Light: squares. The broken line is the linear regression for all data points.

Anisocoria for Repeat Subjects

Subjects in the repeat group were run at least five times in identical sessions. Figure 5 shows the average value of anisocoria (±SD) for each subject in each condition. (The conditions in Figure 5 are not arranged according to the sequence of the protocol but in a sequence approximately corresponding to increasing anisocoria in the population study.) The repeat subjects are partitioned into a group of five plotted at the top of Figure 5, with a separate subject (circles) plotted at the bottom. The latter subject showed a relatively constant, clinically observable, level of anisocoria in all conditions, except for a somewhat smaller amount in the Settled-Dark condition.

The trends we noted in the population survey (Figs. 2–4) are to some extent visible in Figure 5 (top); namely, that the Settled-Dark and Near-Dark conditions produced somewhat more anisocoria. Several conclusions may be drawn from these data: (1) an increase in the average value of anisocoria occurred for two of five subjects in the Near-Dark and Settled-Dark conditions; and (2) the variability of anisocoria (measured by the SD for an individual subject) also showed some tendency to increase in the dark conditions; for example, the subject represented by the filled triangles showed a greater SD in the Initial-

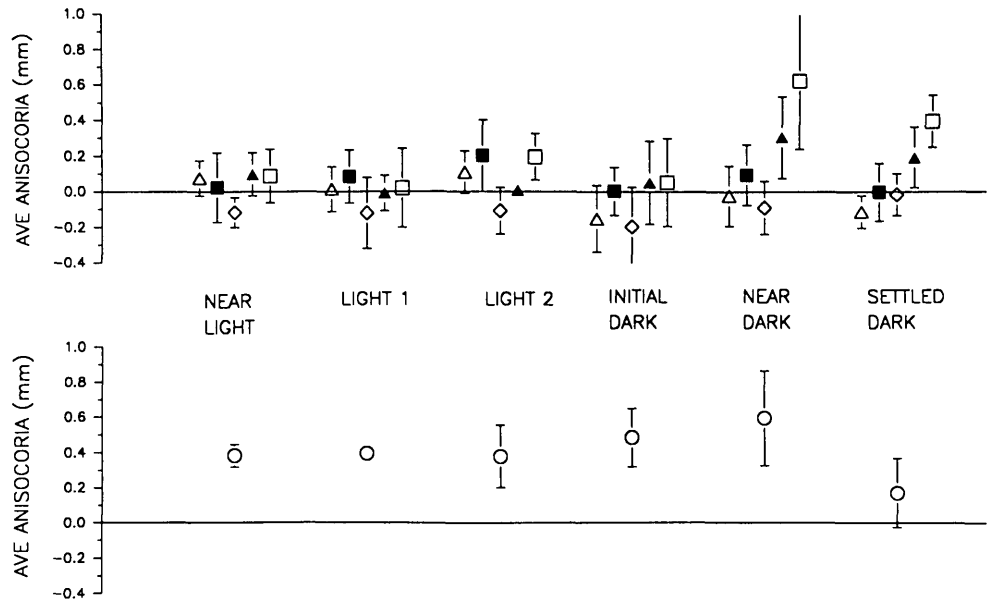


Fig. 5. Results for the repeat group of subjects: for each condition, SD and average value of anisocoria are plotted for each subject. The subject shown separately in the lower graph had a relatively constant anisocoria.

Dark condition than in any light condition although the average value of anisocoria in the Initial-Dark condition was nearly zero. Not all subjects showed this trend clearly (filled and open triangles showed it; open squares showed it to some degree; and filled squares and diamonds did not show it). Interestingly, the repeat subject with relatively fixed anisocoria (Fig. 5, bottom) showed larger SDs in the dark than in the light conditions, except for Light-2.

Although there were variations in detail, the data from the repeat subjects suggested a progression as the conditions in Figure 5 were examined in sequence: four of the six subjects showed a tendency for either average anisocoria, or variability (SD) of anisocoria, or both, to increase as we moved from left to right. (This was not a strict sequence for each of the four subjects; moreover it seems that the Near-Dark condition may produce the greatest increase in the average and SD.) A dramatic example of both of these increases was observed for the repeat subject shown by squares in Figure 5 (top): this subject shifted from light-condition values which would probably not be clinically observable to dark-condition values which would.

We noted that the Near-Dark condition seemed to produce unexpectedly large average values and variability of anisocoria, but our sample in this condition was limited and too small to use as a basis for firm conclusions. In fact, over one half of that sample consisted of the repeat subjects. (For the population results, we used the first complete set of data from each repeat subject.) The more detailed information from repeat subjects offered some support: three of six subjects in Figure 5 showed greater average anisocoria and/or a greater SD in the Near-Dark than in any other condition.

Discussion

Our results indicate that the average value and variability of anisocoria vary with conditions of illumination and accommodation. In general, the entire population showed broader distributions and greater average magnitude of anisocoria in conditions that resulted in larger pupil diameters. About one half of the subjects in the repeat group tended to show increased average value and variability of anisocoria in these same conditions.

Our Settled-Dark condition appeared to correspond to the test conditions used by Loewenfeld,[4] and the SD of our anisocoria data (0.24 mm, Fig. 2) was comparable to the SD she found (0.27 mm, calculated from Fig. 8).[4] Our distributions were narrower than those of Loewenfeld[4] and Lam et al.,[6] a consequence of using the area-derived measures; the SD of anisocoria in the Settled-Dark condition using directly measured diameters was 0.27 mm. The finding of less anisocoria for area-derived diameters was not a consequence of, for example, smaller vertical than horizontal diameters producing a scale factor; area-derived diameters were very close to directly measured ones. (In fact, area-derived diameters were very slightly larger, about 0.03–0.10 mm on average.) Presumably, a contributing factor was the greater variability in direct measurement of diameter. However, slight monocular changes in pupil shape may sometimes occur with little change in area (eg, negatively correlated changes in horizontal and vertical diameter).

Physiologic anisocoria is probably a consequence of one of the following: balance of activity and mechanical factors.

Balance of Activity

Greater environmental illumination and/or greater near effort shifts the balance of pupil innervation from sympathetic toward parasympathetic. We observed a trend toward greater anisocoria in dark states; this would agree with either an imbalance in sympathetic innervation as suggested by Rosenberg[7] or an imbalance in supranuclear inhibition of the parasympathetic component of the oculomotor nuclear complex as suggested by Loewenfeld.[4] (If the sympathetic level were manifested by inhibitory effects on the oculomotor nucleus, these two could be equivalent.)

Mechanical Factors

Alternatively, anisocoria could result from passive mechanical properties of the iris structure. For example, if the fibrous stroma hindered dilation of one iris more than the other, anisocoria would appear and increase as pupil diameter increased. The rarity of anisocoria when the pupils are small suggests that whatever mechanical factors may be involved in anisocoria are less apparent in such conditions. (A dependence of pupil mobility on diameter has been described, with greatest mobility at intermediate diameters.[8–10] Our results for the repeat subjects suggest that anisocoria might be greatest at intermediate diameters; however, in the population results, anisocoria was not significantly different in the Initial-Dark and Settled-Dark conditions.) In any case, structural explanations are not plausible for cases of anisocoria which have been described as reversing signs over time.[4] Of course, a combination of activity balance and mechanical factors might underlie the presence or absence of anisocoria. For example, unequal innervation might be present in a condition producing small pupils but be masked by a symmetric limitation on mobility.

"Dilation Lag" and Anisocoria

Anisocoria in Horner's syndrome and physiologic anisocoria are both associated with greater anisocoria in the dark than light. In Horner's syndrome, the more miotic pupil initially dilates more slowly, creating maximum anisocoria several seconds after the illumination is extinguished, called "dilation lag."[5] This corresponds to the time of the maximum sympathetic role in redilation,[5,11] and our Initial-Dark condition was designed to sample anisocoria at this time during redilation. We found no indication of increased anisocoria in the Initial-Dark condition, which argues against imbalances in sympathetic innervation as the cause of physiologic anisocoria. (It is possible, however, that there is more asymmetry in sympathetic activity in the steady state than during redilation. Dynamic anisocoria is present during the light reflex to monocular stimulation, with the direct reflex slightly greater than the consensual.[12,13] This does not appear in the steady state, which suggests a qualitative difference in parasympathetic innervation during contraction versus the steady state.)

Occurrence of Anisocoria and Its Observation in the Clinic: A Probabilistic View

In the clinic, pupil equality is typically evaluated by measuring the diameter of each pupil directly, either with a ruler or by comparison to a series of half-discs. To be detected clinically, the anisocoria must exceed the threshold of an examiner. For each of our conditions, the results for a population were reasonably well represented by a normal distribution. This provides a useful way to consider the clinical observation of physiologic anisocoria in a population of subjects. If a particular threshold for clinical observation of anisocoria is assumed (eg, 0.4 mm) and if each condition is represented by a normal distribution of anisocoria, then the fraction of patients described as anisocoric will correspond to the area in the "tails" of the distribution (for that condition) lying beyond the threshold (Fig. 6 (top left), where "T" is the threshold. Patients with magnitudes of anisocoria less than T would be described as isocoric.

For a given threshold, conditions which produce broader distributions will produce a greater probability of identifying anisocoria. (Of course, it is also true that for a given distribution, a smaller criterion will also give a greater probability.[6]) As shown in Figure 6 (left), if the same threshold is applied to two distributions with different widths, the broader distribution will have a larger fraction of its area in the tails, classified as anisocoric. It is a property of normal distributions that the area in the tails is very sensitive to the width of the distribution: modest changes in SD can dramatically increase or decrease this area. Figure 6 (right) plots the fraction of the area in a normal distribution (centered at zero) lying outside of a selected threshold, as a function of the SD of the distribution in mm. Curves are shown for three threshold values (0.3, 0.4, and 0.5 mm), which are in the range of those usually assumed to apply for clinical determination of anisocoria. Similarly, the range of SDs (0.0–0.5 mm) covers the range of those found in our population results (0.16–0.45 mm, Fig. 2). It may be seen that as the SD increases above about 0.1 mm, the probability of lying outside of the threshold ("*P*(aniso)"), increases sharply. For example, the probability for the middle curve (0.4-mm threshold) is nearly zero for SD = 0.1 mm, 5% for SD = 0.2 mm, and nearly 20% for SD = 0.3 mm.

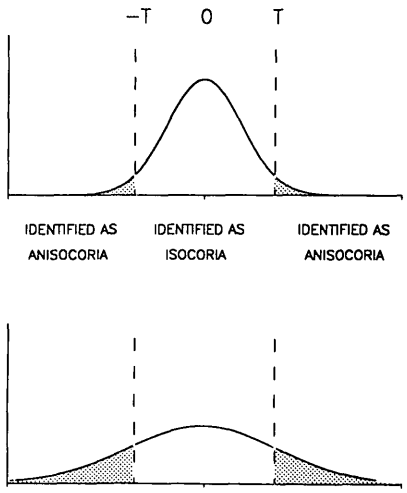
The triangles in Figure 6 were drawn from our population data. For each condition, we measured the fraction of subjects whose anisocoria exceeded 0.4 mm and plotted the fraction against the population SD for that condition. The experimental points lie reasonably close to the theoretic curve for a 0.4-mm threshold, which supports the representation of each condition by a normal distribution. We also included data based on directly measured diameters (filled circles), obtained similarly. Although we mainly reported area-derived measurements, direct measurements were also in reasonable accord with normal distributions. (As noted previously, the distributions of anisocoria are usually somewhat broader for directly measured than for area-derived diameters; thus, the arguments presented here apply to both—if anything, more emphatically to direct measurements.)

Relationship of Data for Individuals to Data for the Population

The data from our repeat subjects show that increases in anisocoria in the general population behavior are likely to arise from two factors that can be separated by repeated measurements of an individual: increased average amount of anisocoria and increased variability of anisocoria (SD over repeated trials). Without going into a detailed analysis, it is generally true (at least, in situations where average anisocoria is less than the threshold) that an increase in average or either in SD will result in an increased likelihood of observing anisocoria greater than a specified threshold.

Clinical Application

In the clinic, the examiner usually cannot repeat measurements in different dark/light and near/far conditions; a brief inspection of a patient's pupils must suffice to determine whether or not anisocoria



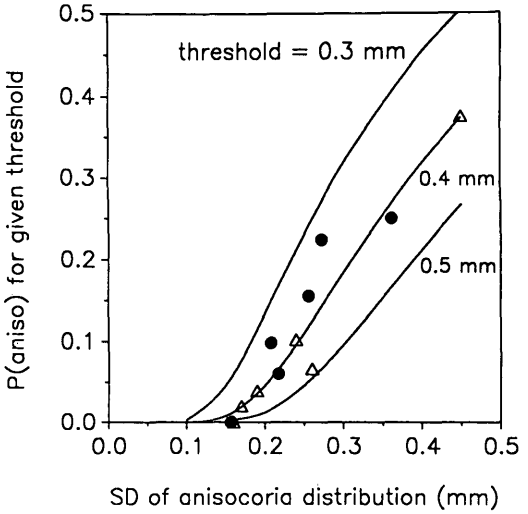


Fig. 6. Probability of observing anisocoria in a normally distributed population. Left: physiological anisocoria in a population is shown as a normal distribution; anisocoria detected clinically can be approximately represented by the area under the distribution curve beyond a particular threshold value, T (eg, 0.4 mm), ie, the shaded area in the "tails." Here, for a narrower (top left) the wider (bottom left) distribution, the areas corresponding to identified anisocoria are the shaded areas. Note that a moderate increase in the distribution width can make a large difference in the fraction of the distribution identified as anisocoric. Right: the fraction of a normal distribution which falls outside a given threshold is plotted against the SD of the distribution. Curves are shown for three values of the threshold—0.3, 0.4, and 0.5 mm. The fraction outside the threshold ("P(aniso)") is the fraction of the population which is identified as anisocoric, given the particular threshold. Modest changes in SD can cause dramatic changes in the fraction identified as anisocoric. (Triangles and filled circles are taken from the population data using a 0.4 mm threshold. Triangles: area-derived diameters [as Figs. 2–6]; circles: directly measured diameters. See text.)

is present. The standard clinical condition used is dim illumination with distance fixation[14] to prevent accommodative and light responses from interfering with observations. Our results suggest that these dim conditions increase the likelihood of observing physiologic anisocoria with a given criterion. A further consideration, however, is that the same condition appears to give substantial variability for a given patient, as judged by our repeat subjects; thus, anisocoria is more likely to be observed, but it is likely to be different on different visits. (This is clearly related to the variable findings of Lam and co-workers[6] for subjects examined at different times under the same conditions.) These observations suggest that dim conditions increase the likelihood of observing physiologic anisocoria, but a single observation of "isocoria" under these conditions does not preclude the possibility of small levels of anisocoria, if rechecked.

One problem with dim illumination is that at some point the observer's ability to distinguish pupil diameters will be degraded; if the level of lighting is reduced enough, the observation threshold of the examiner making the psychophysical judgment will be impaired, and the likelihood of detection will be decreased. (Sometimes added side illumination is used for assessing pupil diameters without eliciting much light reflex.) Another method of keeping the observer sensitive without affecting the pupil system would be to observe the pupils with a cobalt light, such as a Burton lamp, in which the pupil edge may be seen against lens fluorescence without causing much pupil contraction.[15] This might be particularly useful if one is assessing initial redilation after brighter illumination is turned off, since the observer is typically not dark adapted at the time of such an inspection.

We suggest that a first observation of a patient be made under the dimmest room light in which the observer can clearly see both the edges of the pupils and the semicircles on the ruler; the room light can then be turned up for a second comparison of pupil sizes. If the pupils are isocoric in the first and second observations, then there is a good chance that clinically observable levels of anisocoria are not present. If the pupils are isocoric in the first, but not the second observation, then the pupils should be rechecked in the dimmer condition. Our results suggest that it would be very unusual to observe significantly more physiologic anisocoria in the brighter than the dimmer condition. On the other hand, moderate anisocoria in the dimmer condition but less or none in the brighter would fit the general trend that we observed for physiologic anisocoria. If anisocoria is observed with these procedures, the standard methods of determining the cause of anisocoria should be followed.[1,2]

A final point concerns the practice of having a patient presenting with anisocoria bring in old photographs to investigate the history of anisocoria. Different conditions of lighting and accommodation in old photographs could result in differences between cur-

rent and past observations of anisocoria; therefore, the use of old photographs is most valid when they agree with current observations of anisocoria. If an anisocoric patient appeared isocoric in an old photograph, either (1) a genuine change may have occurred, or (2) the photograph may have been taken under conditions which minimize the observability of anisocoria. Further evaluation in such a case would be necessary.

Key words: pupil, anisocoria, physiologic anisocoria, isocoria, observer thresholds, pupil equality

References

1. Thompson HS and Pilley SF: Unequal pupils: A flow chart for sorting out the anisocorias. Surv Ophthalmol 21:45, 1976.
2. Czarnecki JS, Pilley SF, and Thompson HS: The analysis of anisocoria. Can J Ophthalmol 14:297, 1979.
3. Thompson HS: Segmental palsy of the iris sphincter in Adie's syndrome. Arch Ophthalmol 96:1615, 1978.
4. Loewenfeld IE: "Simple, central" anisocoria: A common condition seldom recognized. Trans Am Acad Ophthalmol Otolaryngol 83:832, 1977.
5. Pilley SF and Thompson HS: Pupillary "dilatation lag" in Horner's syndrome. Br J Ophthalmol 59:731, 1975.
6. Lam BL, Thompson HS, and Corbett JJ: The prevalence of simple anisocoria. Am J Ophthalmol 104:69, 1987.
7. Rosenberg ML: Physiological anisocoria: A manifestation of a physiologic asymmetry of sympathetic tone. ARVO Abstracts. Invest Ophthal Vis Sci 29(Suppl):79, 1988.
8. Loewenfeld IE and Newsome DA: Iris mechanics: I. Influence of pupil size on dynamics of pupillary movements. Am J Ophthalmol 71:347, 1971.
9. Semmlow J, Hansmann D, and Stark L: Variations in pupillomotor responsiveness with mean pupil size. Invest Ophthalmol 15:85, 1975.
10. Usui S and Stark L: Sensory and motor mechanisms interact to control amplitude of pupil noise. Vision Res 18:505, 1978.
11. Lowenstein O and Loewenfeld IE: Mutual role of sympathetic and parasympathetic in shaping of the pupillary reflex to light. Arch Neurol Psychiatry 64:341, 1950.
12. Smith SA, Ellis CJK, and Smith SE: Inequality of the direct and consensual light reflexes in normal subjects. Br J Ophthalmol 7:523, 1979.
13. Wyatt HJ and Musselman JF: Pupillary light reflex in humans: Evidence for an unbalanced pathway from nasal retina, and for signal cancellation in brainstem. Vision Res 21:513, 1981.
14. Gray L: The pupil evaluation. *In* Ocular Disease: Detection, Diagnosis, and Treatment, Terry JE, editor. Springfield, IL, Charles C. Thomas, 1984, pp. 288–313.
15. Alexander LJ: Use of "black light" in assessing pupillary responses. Am J Optom Physiol Optics 54:792, 1977.