bodies similar to those seen in this study are indicative of a pathologic state[1, 3] or may be related to the aging process.[1, 2] Others maintain that such inclusions in EOM are normal[2, 4] and unrelated to aging.[4] The present observation of such cytoplasmic inclusions in normal prepubertal rabbit is compatible with the latter opinion.

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Preferential looking acuity obtained with a staircase procedure in pediatric patients.

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Visual acuity of infants and young children with ophthalmologic disorders was assessed by adapting a transformed up-down staircase to preferential looking (PL) procedures. Eighty-five percent of pediatric patients between 11 days and 5 years of age were tested successfully. Acuity of infants and young children with normal eyes obtained by the PL staircase procedure agreed well with acuities obtained previously by the method of constant stimuli. In children with anisometropia, differences in acuity between eyes varied systematically with the amount of anisometropia. Monocular acuities of untreated patients with strabismus did not always agree with fixation preference. In general, test results from pediatric patients with structural ocular abnormalities were consistent with the severity of the disorder. By means of serial measurement of PL acuity, the therapy of patients with amblyopia was monitored. In our young patients, anisometropic amblyopia affected grating acuity differently than did strabismic amblyopia, as others have reported in older patients with these conditions. Our results indicate that the PL staircase procedure provides a useful measure of visual acuity in pediatric ocular disorders that can complement the clinical evaluation of infants and young children. (INVEST OPHTHALMOL VIS SCI 23:538-543, 1982.)

Assessment of visual acuity has been proposed as an aid in the detection and management of ocular disorders in infants. Preferential looking (PL), a technique based on infant looking behavior, has been used to study visual acuity in infants.[1] Several methods of acuity estimation by PL have been proposed but have disadvantages for clinical application. The method of constant stimuli (MCS)[2] is too lengthy for most clinical purposes. The diagnostics stripes procedure, developed for clinical screening,[3, 4] does not yield a direct estimate of acuity and hence is not sensitive enough, at least in young infants, to detect or follow the course of ocular disorders.[5] A recently reported quick method[6] has unusual psychometric properties[7–9]

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that could limit its clinical value. Nevertheless, because PL can be integrated readily into the ophthalmic examination of pediatric patients and can contribute to the patient's evaluation,[5, 10] we have continued to develop PL for clinical application. We here report use of a staircase method[11] that has relatively well-defined statistical properties[12] in conjunction with two-alternative forced-choice preferential looking procedures[13–15] to test visual acuity in young patients.

Methods. Detailed descriptions of our PL apparatus and basic procedures were reported previously.[3, 13] The infant was shown black-and-white square-wave gratings, on the right or left, paired in the other stimulus position with a very high-spatial-frequency grating (81 cy/deg) that was subthreshold for adults.[13] An adult observed the infant through a peephole centered between the stimulus positions and judged stimulus location, right or left, based on the infant's eye and head movements. An operant modification[13] extended the testable age range from early infancy through the preverbal years. Infants younger than 5 months old were held 32 cm from the stimulus screen and older children were seated 54 cm from the screen. Space-average luminance of the screen and gratings was about 2.0 log cd/m^2.

The staircase rule used for the present procedure was a slight modification of the transformed up-down rule.[11] The initial suprathreshold spatial frequency presented in the staircase (2 to 3 octaves above average threshold for age) was derived from previously determined acuity norms.[14, 15] After two correct responses, spatial frequency was increased by an octave; that is, stripe width was halved. An error on trial N was followed by a suprathreshold grating to keep the child interested in the procedure, and then by a 1-octave decrease in spatial frequency below that used on trial N. Testing continued until three sequences of an error followed by two correct responses occurred. This rule resulted in staircases of 20 to 25 trials (excluding the added suprathreshold gratings). The staircase was scored taking the geometric mean of all stimulus values presented, excluding the first three spatial frequency levels and the suprathreshold gratings presented after errors. The value obtained by the transformed up-down procedure corresponds to the 70.7% correct point on the psychometric function.[11] The statistical properties of staircases employing the transformed up-down rule have been studied by means of computer simulations.[9, 12] Using these studies as a guide, we considered an acuity difference of one octave between the two eyes to be significant.*

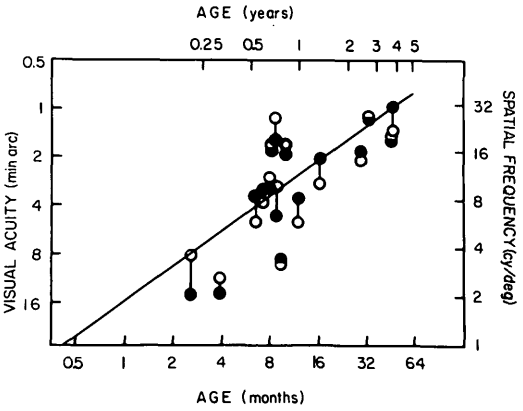

Fig. 1. PL staircase results for infants and children with normal eyes and no high or unequal refractive errors. The spherical equivalents for the 32 eyes represented in this graph ranged from −1.00 to +5.00 D. Results from each child are represented by a filled circle for the right eye and an open circle for the left eye connected by a line. In no infant was the difference in acuity between eyes significant; the mean difference, proportional to the better eye was 0.3 octave (S.D. = 0.2 octave). The regression line was fit by the least-squares method. The slope and intercept of the line were not significantly different from those obtained by analysis of binocular thresholds (70% criterion) with MCS in 2-week-old children to 5-year-old children (slopes, $t = 1.45$, $df = 151$, $p > 0.10$; intercepts using adjusted treatment mean square, $t = -0.72$, $df = 151$, $p > 0.40$) (data obtained from Allen[14] and Mayer[15]).

This report is based on the results of PL staircase tests in 343 consecutive patients, ages 11 weeks to 5 years (mean 20 months), who had a variety of ocular conditions. Results from patients

*For staircases of 25 trials using 1-octave step sizes, the standard error of estimation of the transformed up-down method is about 0.8 σ, where σ is the standard deviation of the cumulative normal curve assumed to describe the psychometric function.[9, 12] In infants under 12 months of age, σ is about 1 octave on the average,[14, 15] while in older infants and children, σ is 0.5 to 0.75 octave on the average.[15] Thus staircases of 25 trials should provide an estimate of the 70.7% level to within a standard error of about 0.8 octave for younger infants and 0.4 to 0.6 octave for older children.

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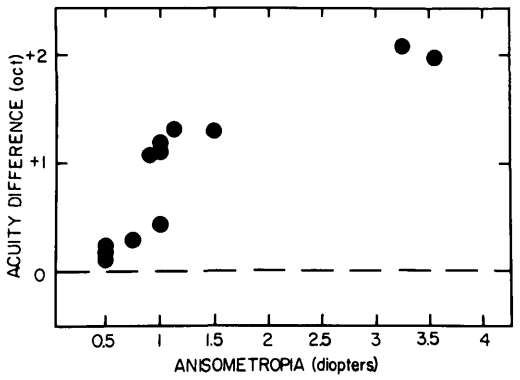

Fig. 2. Differences between right eye and left eye PL staircase acuities as a function of the amount of anisometropia. These patients had no major ocular abnormalities and at least 0.5D difference in spherical equivalent between eyes. Each point represents results from one child. The ordinate gives the difference, in octaves, between monocular acuities proportional to the better acuity, and the abscissa gives the difference between eyes in spherical equivalent. The acuity difference between eyes increased with increasing anisometropia (rank correlation, $r_s = +0.96$, df = 10, $p < 0.01$).

with the frequently encountered categories of pediatric ophthalmic disorders—anisometropia, strabismus, and structural ocular abnormalities—were selected and analyzed separately. All patients' ophthalmic examinations included evaluation of the external ocular structures, alignment and motility, cycloplegic retinoscopy, and indirect ophthalmoscopy. PL testing was done before administration of dilating drops. Monocular testing was accomplished by covering one eye with an adhesive eye patch. Differences in acuity between eyes or between tested and normal acuity were recorded in octaves proportional to the better acuity.

Results. Eighty-five percent (291) of the 343 patients were successfully tested. Those who could not be tested were very ill, too sleepy, or restless. Most of these patients (309, 90%) were too young or otherwise impossible to evaluate with standard acuity tests (Allen cards, the "E" game, or Snellen letters). In alert, cooperative patients, testing was completed (that is, an acuity was obtained from each eye) within 20 min.

The results from 16 patients whose ophthalmic examinations revealed no abnormalities are shown in Fig. 1. As with binocular results,[13, 14] normal monocular acuity improved with increasing age. Acuity differences between eyes in these infants likely represent random variation because in none was the acuity difference greater than 1 octave. The age trend shown by the best fit line to the monocular values (Fig. 1) agreed well with binocular values established previously using the MCS.[13, 14]* Most of the monocular acuities were within one octave of the predicted mean value for age. We consider the limit for "normal" acuity to be 1 octave below the predicted mean value for age.†

PL staircase acuities were obtained from 12 patients, ages 5 to 60 months (median 19 months), with anisometropia. Each patient had a difference of at least 0.5D spherical equivalent between eyes but no major ocular abnormalities. Before treatment, the acuity difference between eyes varied systematically with the amount of anisometropia (Fig. 2). In each patient the eye with the better acuity was the more emmetropic. Seven of the nine patients with >0.5D of anisometropia had significant acuity differences (>1 octave), whereas the three patients with only 0.5D anisometropia did not have significant acuity differences between eyes. Serial measurements showed that optical correction alone reduced significant acuity differences between eyes in a 6-month-old infant with 1.5D anisometropia, a 22-month-old child with 3.5D anisometropia, and a 4-year-old child with 0.9D anisometropia. However, a significant acuity difference remained despite optical correction of a 5-year-old child with 3.5D anisometropia. Amblyopia was diagnosed in this patient and occlusion therapy is ongoing. Thus PL grating acuity is a sensitive index of visual deficits secondary to anisometropia greater than 0.5D, whether due solely to the refractive error or to amblyopia.

Nineteen strabismic patients without large refractive errors (mean spherical equivalent +1.0D; <0.5D anisometropia) or other eye or systemic abnormalities were tested before occlusion, optical, or surgical treatment. Their ages ranged from

*We compared PL staircase and MCS acuity values in eight normal subjects, ages 2 to 12 months. The mean of the two acuity estimates in these infants differed by only 0.3 octave (paired t test = 0.77, df = 7, $p < 0.25$).

†Analysis of the prediction limits for binocular acuity of 2- to 24-week-old infants obtained by the MCS (Allen J, Mayer DL, and Lepper K, manuscript in preparation) indicated that the range of normal acuity should be about ±1.5 octave, somewhat larger than the range we chose.

3 to 21 months (median 9 months). Thirteen were congenitally esotropic, one was congenitally exotropic, one had acquired esotropia, and four had intermittent exotropia. Four infants with strabismus (ages 6.5 to 8.5 months) had a fixation preference for one eye; three of these infants had congenital esotropia and had no significant difference in acuity between eyes, whereas the other infant, with congenital exotropia, had an acuity difference of 1.4 octave. A diagnosis of presumptive amblyopia was made in this exotropic infant at age 8 months (based on fixation preference) and occlusion therapy was begun. Under a regimen of part-time occlusion, PL acuities became equal by age 12 months. Among the 15 infants who had no fixation preference, only one, an infant with congenital esotropia, had a significant difference in acuity. When tested at 3 and 4 months, acuity differences were 1.1 and 2.5 octaves, respectively. On the basis of the PL results, occlusion therapy was begun at age 4 months, and by age 7.5 months the infant's acuities were equal. These results illustrate that in infants with strabismus, monocular acuities do not always agree with fixation preference, and that when monocular acuity differences are present, they are reduced or reversed by occlusion therapy, a finding consistent with reports of others.[10]

PL acuity data in 39 patients with structural abnormalities of one or both globes (61 of 78 eyes) (Table I) paralleled, in general, the severity of the disorders. Within each diagnostic category, a range of severity was represented. For example, cataracts varied from tiny off-axis opacities to nearly total opacification of the lens. Severe disorders such as dense cataracts, macular colobomas, or marked optic nerve atrophy were associated with acuity that was at least 3 octaves poorer than normal, whereas mild abnormalities such as minor iris anomalies were associated with normal acuity. In most cases between the extremes of mild and severe abnormalities, the degree of acuity deficit and severity of the disorder corresponded well. There were exceptions, however. For example, acuities obtained from two young monocularly aphakic patients at 17 and 27 months of age were somewhat better than expected based on their ocular disorders. The 17-month-old child, with unilateral surgical aphakia from 12 months of age and, in addition, a major malformation of the optic nerve ("morning glory disc"), which produces marked visual deficits in older patients, had PL acuity of 20/90 (1.5 octave poorer than normal). PL acuity of the 27-month-old child, whose unilateral congenital cataract had been aspirated from a mildly microphthalmic eye at 3.5 months, was 20/80 (1.3 octave poorer than normal). The latter patient was tested serially up to 38 months of age, and in that period his absolute acuity remained unchanged. In other words, his visual acuity progressively deviated from normal; it was 2.0 octaves poorer than normal at 38 months. Thus, although the PL staircase reflected the degree of disorder in most cases, the age and the presumed degree of ocular development as well as the particular ophthalmologic disease also influenced the acuities of these patients.

Table I. Structural ocular abnormalities

	Patients	*Eyes affected*
Anterior segment		
Iris and angle anomalies	4	7
Corneal scars	3	5
Cataracts		
Unilateral	6	6
Bilateral	2	4
Posterior segment		
Microphthalmia		
With congenital cataract	1	1
With optic nerve hypoplasia	1	1
Coloboma of iris and choroid	6	10
Persistent hyperplastic primary vitreous	1	1
Cicatricial retrolental fibroplasia	3	6
Macular scars	2	3
Generalized retinal degeneration	2	4
Radiation retinitis	1	2
Optic nerve		
Atrophy	2	3
Hypoplasia	4	7
"Morning glory disc"	1	1
Total	39	61

Discussion. A PL staircase procedure with well-described statistical properties enabled testing of visual acuity in patients from the early postnatal weeks throughout infancy and early childhood. The staircase provided estimates that agreed well with thresholds previously obtained by the lengthier MCS in infants and children with normal eyes.

In children with anisometropia the difference in PL acuity between eyes was correlated with the difference in refractive error between eyes. Acuities became equal after optical correction in two infants with moderate anisometropia and in a 4-year-old child with mild anisometropia, but optical correction alone was not sufficient treatment for a 5-year-old child with a high degree of aniso-

metropia. Therefore the PL acuity staircase appears to be sensitive to anisometropic amblyopia, which often escapes detection until school age unless accompanied by strabismus. Thus it may also be effective in detecting this vision disorder in a population of preverbal children at risk for amblyopia. In addition, because of its sensitivity, the PL acuity staircase procedure could provide a method to study the "sensitive period" for human refractive amblyopia.

A strong association between fixation preference and PL acuities was not found in infants with strabismus who were tested before treatment. Fixation preference may precede acuity differences in strabismus, as reported by others.[10] However, in one young infant with congenital esotropia, we found the opposite: an inequality of acuities was detected before fixation preference became apparent.* The diagnosis and management of amblyopia in preverbal children usually depends on fixation preference. However, these results and others[10] show that visual acuity assessment can increase the precision of occlusion therapy.

Our data show that the visual resolution of infants with certain structural ocular abnormalities is less impaired than that of older children and adults with the same abnormalities. In a patient in whom the structural defect is stationary and for whom amblyopia is not an issue (as in the 27-month-old child with surgical aphakia), acuity will become progressively poorer than normal as the infant grows. If the age at which an asymptotic level of acuity is reached can be determined, management of such patients may be improved. Thus, for example, occlusion therapy to treat amblyopia would be appropriate before the acuity plateau is reached but continued vigorous therapy may be ineffective thereafter.

We conclude that the PL staircase provides a useful measure of vision in children with ocular disorders. PL acuity assessment complements the clinical examination. In addition, it has potential as a screening device for preverbal children at risk for amblyopia and offers a research method to study pediatric eye disorders. Although there are recognized statistical limitations to shortcut psychophysical procedures employing small numbers of trials,[12, 17] continued efforts to develop PL procedures for clinical application seem warranted.

*Another possible explanation for the lack of correspondence between PL acuities and fixation preference in infants with untreated strabismus may be that sensitivity for high-contrast grating stimuli is relatively unimpaired as it is in some adults and children with strabismic amblyopia.[16] Although this possibility could be investigated, we have no evidence as yet that sensory anomalies in young infants with presumptive amblyopia are similar to those in children or adults with amblyopia.

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