Efficacy of the Pelli-Levi Dual Acuity Chart in diagnosing amblyopia

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Abstract

Purpose: Amblyopia is a developmental disorder of spatial vision for which there is no positive diagnostic test. The present study evaluates the recently developed "Pelli-Levi Dual Acuity Chart" as a positive diagnostic test for amblyopia (Pelli, Levi & Chung, 2004). This chart consists of letters, as usual, on one side and letters in noise on the other. This exploits the finding that, for letters near acuity threshold, noise raises the contrast threshold in the amblyopic eye much more than in the fellow eye. By design, normal observers will have similar acuity when tested with either side of the chart (dual acuity log ratio about zero), whereas an observer with lower-than-normal efficiency (as in amblyopia) will show a marked difference in the dual acuity log ratio. **Methods**: In this study, we use the Pelli-Levi Dual Acuity Chart to measure acuity thresholds in 64 normal eyes and 28 amblyopic eyes. We also measure the effects of viewing distance, defocus, and the use of a pinhole. **Results**: Without a pinhole, the Pelli-Levi Dual Acuity Chart has high specificity but poor sensitivity in distinguishing between amblyopic and normal eyes. However, the use of a 1.5 mm artificial pupil retained the high specificity (95%) and greatly improved the sensitivity (to 90%). **Conclusions**: When used in conjunction with a 1.5 mm pupil, the dual acuity chart is a useful positive test for amblyopia.

Introduction

Amblyopia is a developmental disorder of spatial vision due to discordant binocular input, usually from strabismus or anisometropia during early childhood, that results in a decrease in best-corrected acuity and contrast sensitivity[1]. Currently there is no positive diagnostic test for amblyopia. Instead, amblyopia is diagnosed by exclusion: in patients with conditions such as strabismus and anisometropia, a diagnosis of amblyopia is made through exclusion of uncorrected refractive error and underlying ocular pathology. The present study investigates the recently developed "Pelli-Levi Dual Acuity Chart," which has been proposed as a positive diagnostic test for amblyopia[2].

Both humans and monkeys with amblyopia show reduced efficiency, i.e., poor acuity and contrast sensitivity in noise [2-4]. The Pelli-Levi Dual Acuity Chart (Figure 1) was developed to detect observers with low efficiency at high spatial frequencies. In theory, the legibility of letters in noise could be immune to uncorrected refractive error and other types of optical blur because blur would affect signal and noise equally, leaving the signal-to-noise ratio unchanged[5,6], provided the observer still uses the same spatial frequency channel[7-10].

The left side of the Pelli-Levi Dual Acuity Chart is an ordinary letter acuity chart. The right side has different letters, but is otherwise identical to the left, except for the addition of uncorrelated luminance noise. (All the chart letters are 50% Weber contrast so that noise can be added.) The Sloan letters have equal width and height. The noise is composed of checks: 14.5 X 14.5 checks per letter. All letters on the right side of the chart are at the same signal-to-noise ratio, chosen to be just above the normal threshold.

The in-noise side of the chart exploits the finding that for letters near acuity threshold, noise raises the contrast threshold in the amblyopic eye much more than in the fellow eye. We use the Pelli-Levi Dual Acuity Chart to measure acuity thresholds on adult normals and amblyopes. We also add spherical lenses to measure the effect of defocus on acuity, with and without noise. Finally, we also retested many conditions with a pinhole.

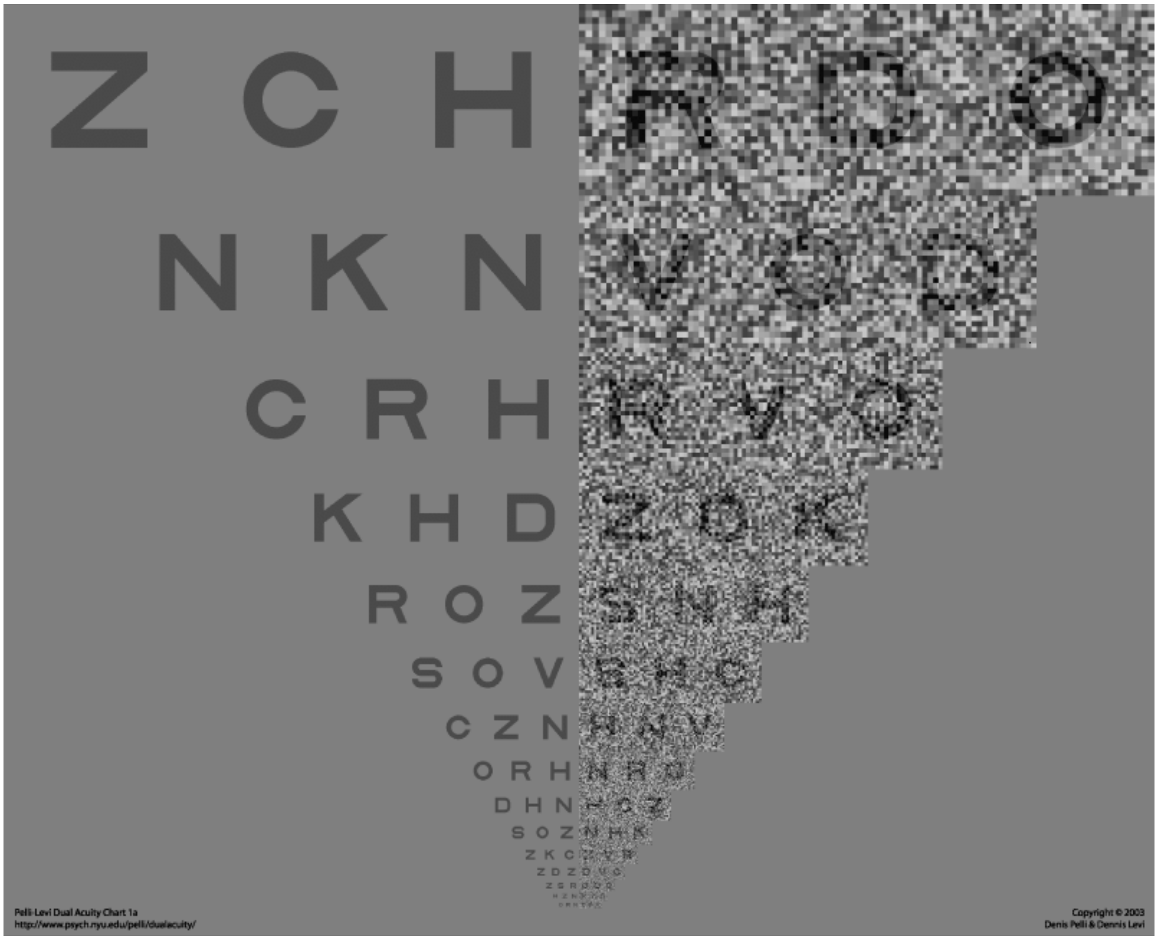

Figure 1. **Pelli-Levi Dual Acuity Chart**: Observers read down the left (no-noise) side of the chart until all three letters in a line are missed. Partial credit (1/3 line) is given for each letter read for any triplet in which a letter was read correctly. Observers read down the right (noisy) side of the chart until all three letters in a line are missed. Again, partial credit is given. The difference in log acuities (i.e. lines) with and without noise is the observer's dual acuity.

Methods

Pelli-Levi Dual Acuity Chart

Observers were asked to read all three letters on the top left (no-noise) side, continuing down the chart (reading only the letters on the left side) until all three letters on one line were missed. Observers were then asked to read all three letters on the top right (in-noise) side, continuing down the chart until all three letters in one line were missed. Partial credit (1/3 line) was given for each letter read correctly. The chart is scale invariant and may be used at any distance the observer can accommodate. The dual acuity *difference score* is specified as the log of the ratio of the acuities measured with and without noise.

General

The Pelli-Levi Dual Acuity Chart was placed on a wall at eye level, and was viewed under normal overhead fluorescent lighting. The letter contrast was 50% and the background had a mean luminance of 27 cd/m^2. To measure dual acuity of the right eye, observers were asked to stand at a specified distance from the chart while occluding the left eye. Observers were asked to read down the left (no-noise) side of the chart, and acuity was recorded. Observers were then asked to read down the right (noisy) side of the chart, and acuity was recorded. To measure dual acuity of the left eye, observers were asked to occlude the right eye and to repeat the procedure.

Normal observers, wearing their full optical correction, were tested at a standard viewing distance of 2 m. Amblyopes were initially tested at 2 m. However, if vision loss precluded acuity measurements at this distance, observers were tested at a viewing distance of 1 or 0.5 m, depending on the severity of their vision loss. This use of different viewing distances across eyes and observers is not of concern because we only compare acuities between noise and no-noise conditions, for the same eye and distance. Provided the observer accommodates equally well at both distances, the scale invariant chart presents essentially the same retinal image at a nearer distance, but extra, easier-to-see, lines are added at the top, as the same number of very-hard-to-see lines are removed at the bottom.

We converted the scores to acuity in degrees (using the known letter sizes in mm and the viewing distance) and calculated the difference acuity score as log acuity with noise minus log acuity without noise.

Observers

In total, we tested each eye of 32 normally sighted observers (64 normal eyes) and 28 amblyopes (7 strabismic, 9 anisometropic, and 12 anisometropic/strabismic) ranging in age from 11 to 57 years. Sixteen normal observers (32 eyes) were tested without pinholes and 16 more (32 eyes) were tested with pinholes. Twelve of the amblyopes were also tested with a pinhole.

Normally sighted observers were tested monocularly at viewing distances of 0.5, 1, 2, and 4 m, and with "fogging" lenses of +0.5, +1, and +1.5 D (all at a distance of 2 m), and with 1 and 1.5 mm pinholes.

The research followed the tenets of the Declaration of Helsinki. The experiments were undertaken with the understanding and written consent of each observer, and all procedures were approved via institutional review.

Results

Power of the chart to separate amblyopes from normals – no pinhole

We began by testing 16 normal observers and 18 amblyopes at several viewing distances without a pinhole. Figure 2 shows dual acuity in observers with amblyopia. Each amblyopic observer's acuity in noise is plotted against his or her acuity without noise. Each amblyopic eye is plotted as a solid circle, each non-amblyopic eye as an open circle, and each normal eye as a small grey circle (Fig. 2A). The reduced acuity of the amblyopic eyes is evident. Most of the amblyopic eyes lie above the 1:1 line, indicating a greater acuity loss in noise than without noise. This effect can be seen more easily in the dual acuity difference scores (Fig. 2B).

We are interested in using the dual acuity chart to distinguish between normal and amblyopic eyes. In choosing a normal/abnormal classification criterion, we trade-off specificity (fraction of normals classified "normal") against sensitivity (fraction of amblyopes classified as abnormal)[11]. Most patients are normal, so, to be useful, a screening test like this must pass nearly all normal eyes. We selected a 95% specificity: 69 of 73 normals are classified as "normal". This is achieved by setting the criterion level of the dual-acuity score to 0.15. The criterion classifies all eyes below it (the gray region in Fig 2) as "normal" and all eyes above it (white region) as "abnormal". At this (reasonable) criterion, the sensitivity is poor (50%), only half of the eighteen amblyopic eyes (solid symbols) are classified as "abnormal". Of these, 4 were anisometropic, 3 were strabismic, and the remaining 2 were both strabismic and anisometropic amblyopes. However, the specificity was good. Only 2 of the 18 non-amblyopic eyes (NAE) were classified as "abnormal".

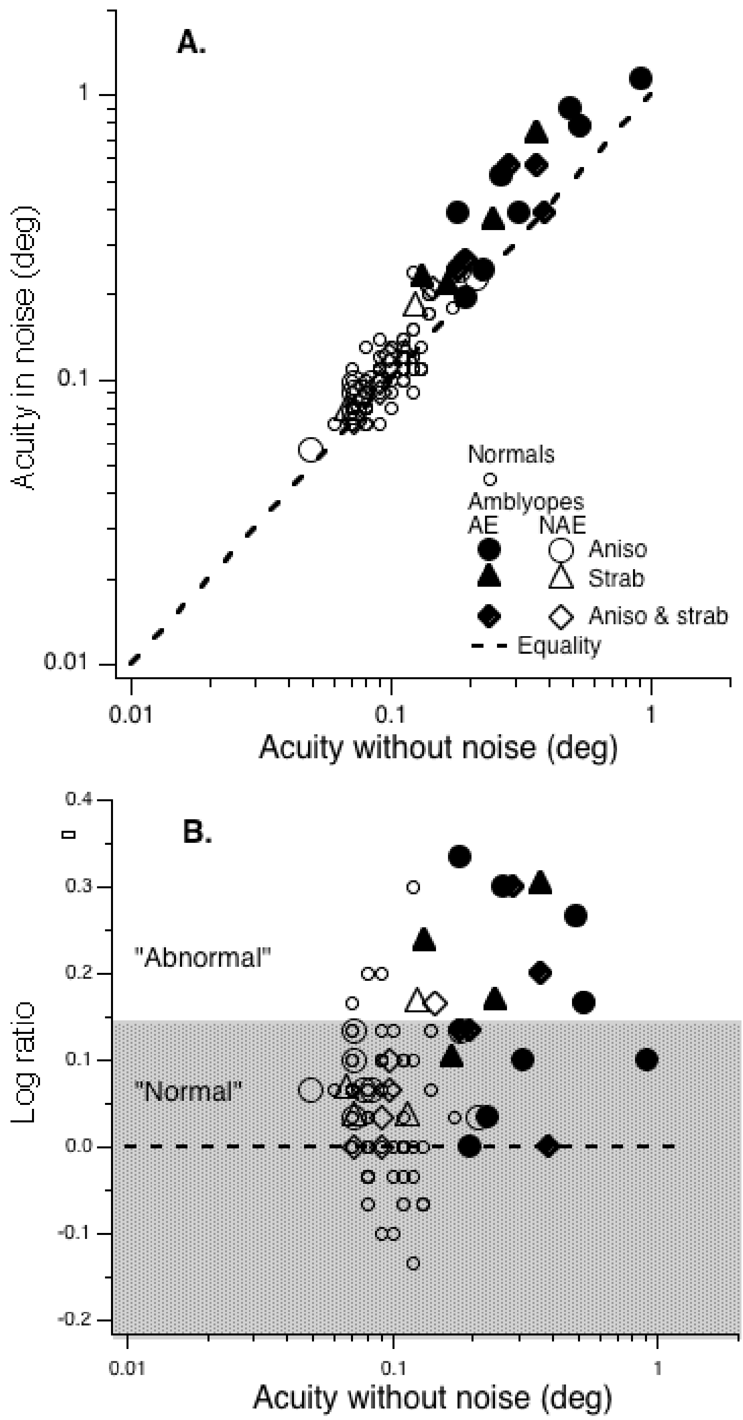

Figure 2. Dual acuity scores of amblyopic (AE), non-amblyopic (NAE), and normal eyes. (A.) Visual acuity (the letter size in degrees) in noise versus without noise. Amblyopic eyes are solid circles, non-amblyopic eyes are open circles, and normals are small grey circles. Different etiologies of amblyopia are coded by symbol type. (B.) The data of A are replotted as dual acuity difference score (log ratio) vs. no-noise acuity. The criterion (0.15) was chosen so that 95% of the normal eyes fall below it (gray region).

Effect of defocus

We thought the dual acuity chart might be immune to the effects of optical blur, but we discover that it is not. Figure 3A shows that optical defocus impairs acuity measured in noise more than acuity measured without noise. This figure plots the mean of the 16 normal observers (two eyes per observer) tested without pinholes at a viewing distance of 2 m.

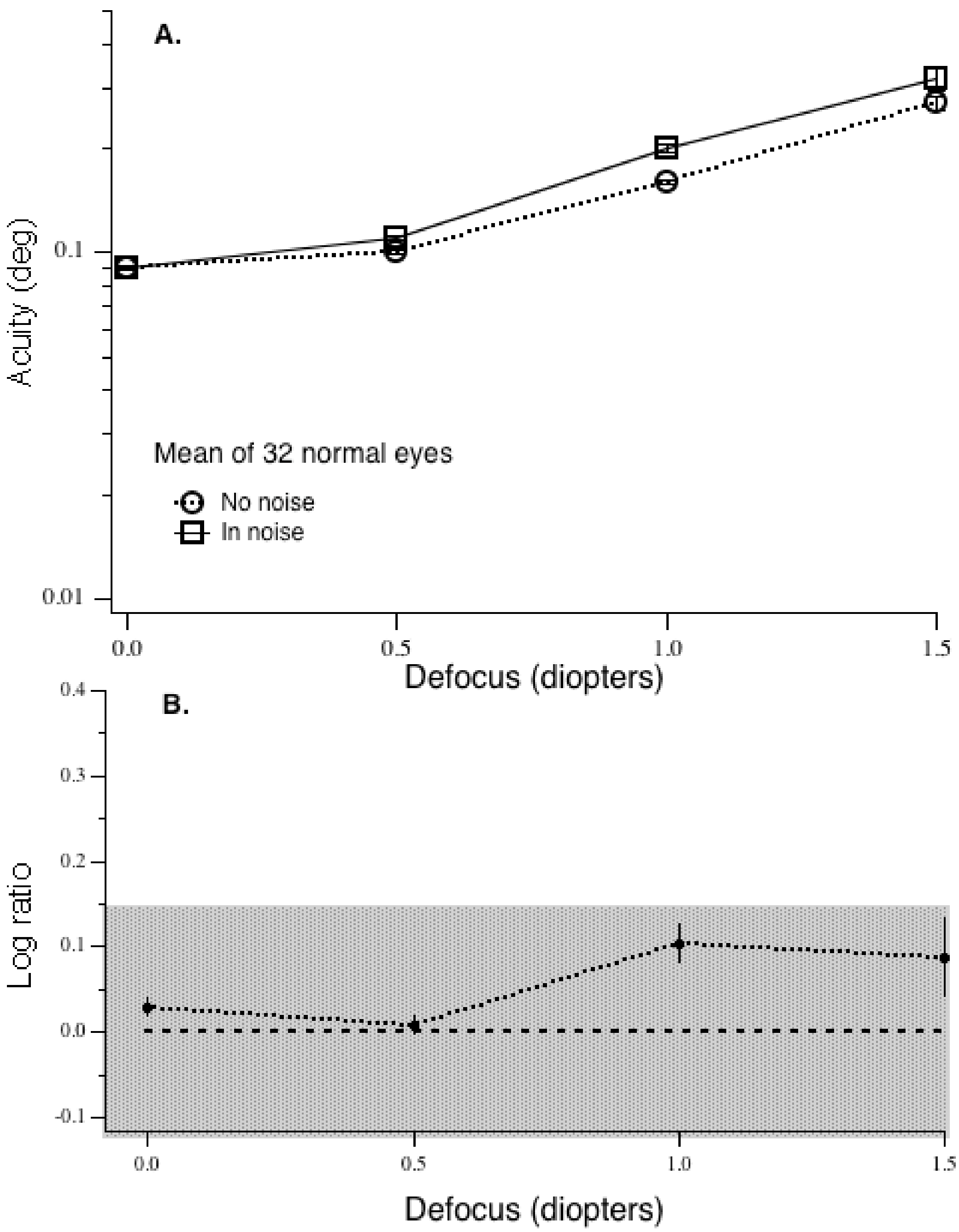

Figure 3. Effect of defocus (introducing a spherical lens). Top: Acuity (deg) with (squares) and without noise (circles) vs. defocus. Each point is the mean of 32 normal eyes tested at 2 m. Bottom: Dual acuity difference score (log ratio) increases with defocus. The gray region contains 95% of the normal eye values with no defocus.

Figure 3B replots the data as the acuity difference score (log ratio). It shows the differential effect of defocus on acuity with noise. For defocus greater than 0.5 diopter, the mean difference score increases substantially, as does the variability of acuity among the observers (as seen by the increasing size of the error bars). However, both effects of defocus can be eliminated by the use of a pinhole as shown below.

Power of the chart to separate amblyopes from normals – with pinhole

The unexpected effect of defocus seen with normal observers raises the possibility that the amblyopic difference scores are also affected by defocus. To assess the extent to which the amblyopes' difference scores are due to optical blur, we tested 16 normal observers (32 eyes) and seven amblyopes using a pinhole. The pinhole reduces the effects of defocus and accommodative fluctuations.[12, 13] We first tested 3 normal observers (6 eyes) and 2

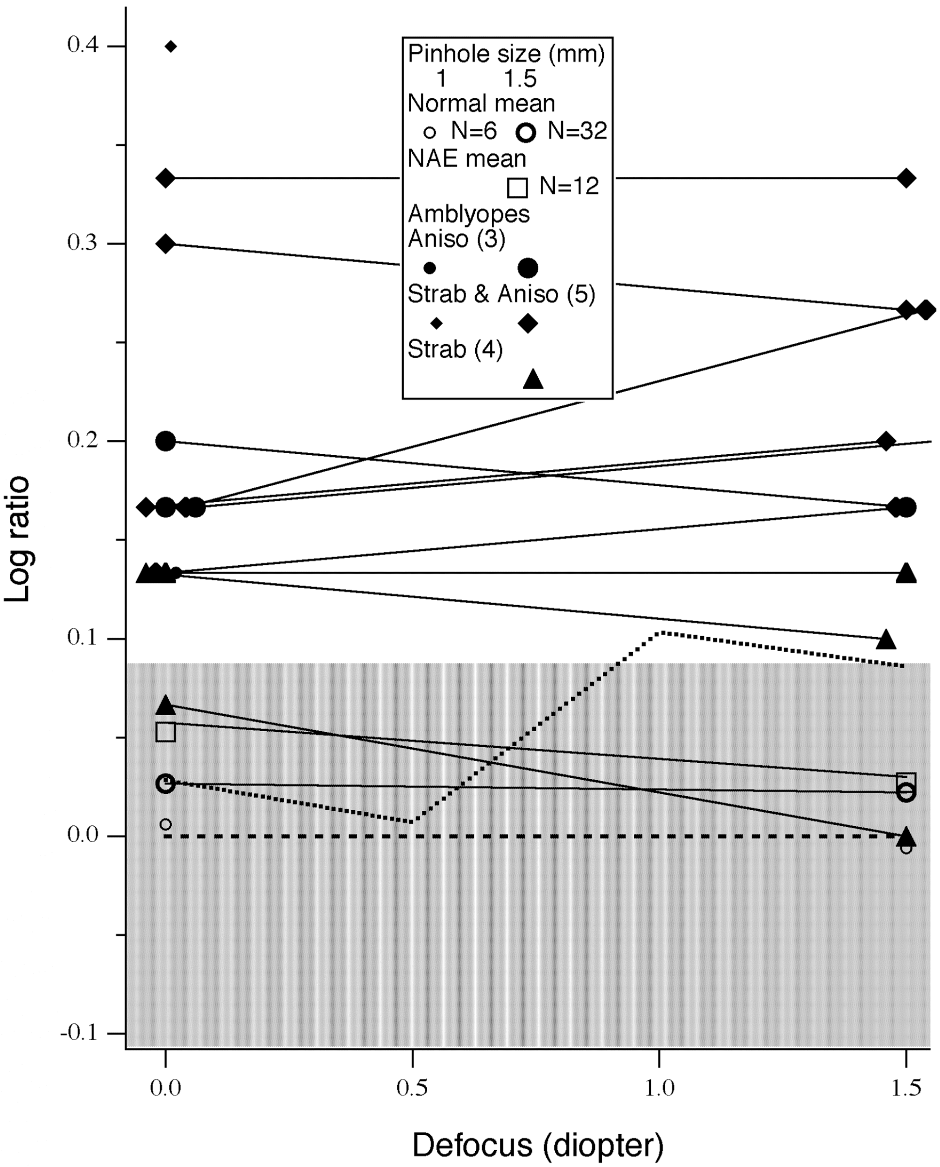

Figure 4. Effect of defocus (introducing a spherical lens) with a pinhole. Difference acuity (log ratio) is independent of defocus for normal (open circles) and nonamblyopic eyes (open squares) when viewing with a 1 or 1.5 mm pinhole.95% of the normal eyes without defocus are in the gray region, i.e. below the new criterion of 0.09. Solid symbols show data of 7 amblyopes with a 1 or 1.5 mm pinhole. The dotted gray line shows the normal ratio with no pinhole from Fig. 3B.

amblyopic eyes with 1 mm pupils. This reduced the normal log ratio to nearly zero, even with 1.5 diopter of defocus (Fig. 4, small open circles), while the amblyopic eyes still showed large difference scores (medium filled symbols). That was encouraging. However, the amblyopes found the acuity measurements difficult with the 1 mm pupil, and the reduced retinal illuminance substantially reduced all of the acuity values. Therefore we retested them (plus ten additional amblyopes) with a larger (1.5 mm) pupil, which they found much easier. We also tested 32 normal eyes using the 1.5 mm pupil (large gray circles). Note that there is now no effect of defocus on the normal and nonamblyopic eyes. The pinhole substantially reduces the variability among the normal eyes, so that for 95% specificity the criterion level is now 0.09. Unlike the disappointingly low sensitivity reported above, now 18 of 20 amblyopic eyes (measured with a 1.5 mm pupil) exceed the (new) criterion and are thus classified as “abnormal”.

Discussion

Normal observers

The present study was designed with three objectives: (1) to determine the efficacy of the Pelli-Levi Dual Acuity Chart in detecting amblyopia, (2) to determine a baseline range for the acuity ratio in normal observers to set an appropriate criterion for classification as “normal” or “abnormal”, and (3) to assess any effects of test distance and optical blur. It was hoped that the chart might be immune to optical blur, but Figure 3 shows that the dual acuity difference score is in fact affected by optical blur. The mean and variability of the difference score grow with blur from 0 to +1.5 D. Thus the Pelli-Levi Dual Acuity Chart is not immune to optical blur. However, introducing an artificial pupil eliminates the effect.

Amblyopic observers

Without a pinhole, 50% of the amblyopic eyes (9/18), 4% of normal eyes (4/73), and 11% of the non-amblyopic eyes (2/18) showed a difference score greater than 0.15. In distinguishing amblyopic from non-amblyopic eyes (i.e. both normal observers and NAE), the Pelli-Levi Dual Acuity Chart, without a pinhole, using a criterion (0.15) that achieves a specificity of 95%, has a disappointingly low sensitivity of 50%.

Our results show that the sensitivity of the Pelli-Levi Dual Acuity Chart is greatly improved by testing all observers with a 1.5 mm pinhole. Adding the 1.5 mm pinhole increases the sensitivity to 90% while maintaining the 95% specificity.

Conclusion

The Pelli-Levi Dual Acuity Chart is a positive diagnostic test for amblyopia. Our results show that this test, as originally published, is statistically weak. At a reasonable specificity (95%), its sensitivity of only 50% is disappointing, failing to detect about half of the amblyopes. We also found, contrary to expectation, that the test is sensitive to defocus. However, adding a 1.5 mm pinhole solves both problems, eliminating the effect of defocus and accommodative fluctuations and greatly reducing the standard deviation of the score, resulting in a sensitivity of 90%, while retaining high specificity (95%).

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References

1. Ciuffreda KJ, Levi, DM, Selenow A. *Amblyopia: Basic and Clinical Aspects.* Boston: Butterworth-Heinemann; 1991.
2. Pelli DG, Levi DM, and Chung STL (2004). Using visual noise to characterize amblyopic letter identification. *Journal of Vision*. 4, 904-920.
3. Kiorpes L, Tang C and Movshon JA (1999). Factors limiting contrast sensitivity in experimentally amblyopic macaque monkeys. *Vision Research*. 39, 4152-60.
4. Nordmann JP, Freeman RD, and Casanova C (1992). Contrast sensitivity in amblyopia: Masking effects of noise. *Investigative Ophthalmology and Visual Science*. 33, 2975-2985.
5. Kersten D, Hess RF, and Plant GT (1988). Assessing contrast sensitivity behind cloudy media. *Clinical Vision Science*. 2, 143-158.
6. Pelli DG, and Hoepner JA (1989). Letters in noise: A visual test chart that "bypasses" the optics. *Noninvasive Assessment of the Visual System, 1989 Technical Digest Series* (Optical Society of America, Washington, DC) 7, 103-106.
7. Solomon, J. A., & Pelli, D. G. (1994). The visual filter mediating letter identification. *Nature, 369(6479),* 395-397.
8. Majaj, N. J., Pelli, D. G., Kurshan, P., & Palomares, M. (2002). The role of spatial frequency channels in letter identification. *Vision Res, 42(9),* 1165-1184.
9. Parish, D. H., & Sperling, G. (1991). Object spatial frequencies, retinal spatial frequencies, noise, and the efficiency of letter discrimination. *Vision Res, 31(7-8),* 1399-1415.
10. Gold, J., Bennett, P. J., & Sekuler, A. B. (1999). Identification of band-pass filtered letters and faces by human and ideal observers. *Vision Res, 39(21),* 3537-3560.
11. Swets, J. A., & Pickett, R. M. (1982). *Evaluation of Diagnostic Systems: Methods from Signal Detection Theory*. New York: Academic Press.
12. Campbell, F. W., & Gubisch, R. W. (1966). Optical quality of the human eye. *Journal of Physiology, 186,* 558-578.
13. Artal, P., Marcos, S., Iglesias, I., & Green, D. G. (1996). Optical modulation transfer and contrast sensitivity with decentered small pupils in the human eye. *Vision Res, 36(22),* 3575-3586. [PubMed]