Published in final edited form as:

Optom Vis Sci. 2010 November ; 87(11): E806–E812. doi:10.1097/OPX.0b013e3181f6fb5e.

Vernier Acuity Cards: Examination of Development and Screening Validity

James R. Drover, PhD, Sarah E. Morale, BS, Yi-Zhong Wang, PhD, David R. Stager Sr, MD, Eileen E. Birch, PhD

Retina Foundation of the Southwest, Dallas, Texas (JRD, SEM, Y-ZW, EEB), Memorial University of Newfoundland, St. John's, NL, Canada (JRD), and Department of Ophthalmology, University of Texas Southwestern Medical Center, Dallas, Texas (Y-ZW, DRS, EEB)

Abstract

Purpose.—Because vernier acuity appears to be limited by the visual cortex, it possesses excellent potential as a clinical/screening tool to detect amblyopia in infants and toddlers. Thus, we developed the vernier acuity cards specifically for this age group. We compared developmental data gathered using this new test and the Teller Acuity Cards (TAC). In addition, we compared the clinical/screening validity of the two tests by testing children old enough to complete optotype acuity testing (6.2 ± 2.5 years).

Methods.—Vernier acuity and grating acuity were assessed in 98 children and 18 adults with normal vision (range = 2.8 months to 35.8 years). The developmental time course of the two visual functions was compared. In addition, vernier acuity and grating acuity were measured in 43 children with amblyopia and 30 nonamblyopic children with an amblyogenic condition. Each child's grating acuity and vernier acuity were classified as normal/abnormal based on age-appropriate norms. These classifications were compared to amblyopia diagnoses by crowded HOTV or ETDRS testing.

Results.—Vernier acuity and grating acuity follow different developmental time courses in normal infants and children. Vernier acuity is initially poorer than grating acuity, but surpasses it by age 5 and is adult-like by age 8. Compared to the TAC, the vernier acuity cards yielded higher sensitivity (81% v. 44%) and similar specificity (73% v. 93%), and was more sensitive to all amblyopia subtypes/levels of severity.

Conclusions.—The developmental time course of vernier acuity differed from that of grating acuity implying that it is not mediated by the retina. Also, the impressive validity of the vernier acuity cards suggests that they are an effective tool for detecting amblyopia.

Keywords

vernier acuity; grating acuity; development; screening; amblyopia

Corresponding author: James R. Drover, Memorial University of Newfoundland, St. John's, Newfoundland A1B 3X9, CANADA, jrdrover@mun.ca.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Spatial localization, the ability to determine the relative position of the elements of a visual stimulus, is critical to pattern perception. It is usually assessed by the measurement of vernier acuity, the finest misalignment that can be detected between two lines/gratings. Vernier acuity is remarkably fine, and in typical adults, is an order of magnitude better than grating acuity.^{1, 2} Whereas grating acuity is limited primarily by photoreceptor spacing, vernier acuity is 5 to 10 times finer than intercone spacing on the fovea. Thus, vernier acuity is typically referred to as a “hyperacuity”,³ and because it extends well beyond the limits of the fovea, researchers speculate that it is likely mediated by the visual cortex.²⁻⁴ Note, however, that although vernier acuity is likely mediated by cortical mechanisms, it also depends on the quality of pre-cortical visual processing, including the contrast sensitivity of ganglion cells and the lateral geniculate nucleus.⁵

There are at least two other lines of evidence that suggest that vernier acuity is mediated cortically. First, developmental data indicate that vernier acuity follows a slow course of maturation that might correspond to that of the visual cortex, which reaches adult synaptic levels at approximately 11 years of age.⁶ Specifically, while grating acuity is adult-like by 6 years of age,⁴ vernier acuity is not yet mature⁷⁻⁹ and may not attain adult level until adolescence.⁴ Second, several studies report that vernier acuity is more sensitive than grating acuity to visual disorders that are cortical in nature.^{10, 11} For example, both adults with strabismic amblyopia and children with cortical visual impairment demonstrate slight reductions in grating acuity, but severe, selective vernier acuity deficits.^{1, 10, 11, 12} Moreover, unlike grating acuity deficits, vernier acuity deficits are nearly linearly proportional to optotype visual acuity deficits in amblyopia.¹³

These latter two findings provide the motivation for the development of a simple vernier acuity test as a clinical/screening tool to detect amblyopia. A test that is more sensitive than grating acuity to the visual deficits associated with amblyopia would be of particular importance for infants and toddlers since there is no gold standard for this age group. The current clinical standard, fixation preference testing, is inadequate because it yields poor sensitivity to cases of amblyopia with small tropias or no misalignment^{14, 15} and a high false positive rate to cases of large angle strabismus.¹⁶ A test of vernier acuity would likely be more sensitive and specific to amblyopia than either of these existing tests for infants and toddlers, and would be a superior tool for the detection of amblyopia.

To address the need for a test that can effectively detect amblyopia in infants and toddlers, we have developed the vernier acuity cards, a test of vernier acuity designed specifically for this age group. Here, we examine the maturation of vernier acuity using this new test and compare its developmental time course to that of grating acuity. In addition, we evaluate the validity of the vernier acuity cards as a clinical/screening tool to detect amblyopia in young children and compare its sensitivity and specificity for amblyopia to that of the Teller Acuity Cards (TAC).

METHODS

Participants

The normative cohort included 98 children ranging from 2.8 months to 17.8 years of age (mean = 7.1 years; SD = 4.4 years). All participants were healthy full-term children who possessed no known eye disease. The ethnicity of the normative sample was representative of the Dallas-Fort Worth area as a whole, 84% Caucasian and 16% minority (i.e., African-American, Hispanic, Asian/Pacific Islander). Some children were tested in more than one age group. For comparison, 18 young adults (mean = 27.5 years; SD = 6.2 years) were also tested.

The patient cohort was composed of 3- to 17-year-old children from two sub-groups: children with unilateral amblyopia (N = 43; mean age = 6.1 years, SD = 3.0 years) and nonamblyopic children with a unilateral amblyogenic factor (strabismus, cataract, and/or anisometropia) (N = 30; mean age = 6.3 years; SD = 2.3 years). Formal diagnoses of amblyopia were based on a ≥ 0.2 logMAR (2-line) interocular difference on HOTV or ETDRS visual acuity with ≥ 0.3 logMAR ($\leq 20/40$) in the nonpreferred eye and the presence of a unilateral amblyogenic factor, which included constant strabismus, anisometropia (≥ 1 D), or a unilateral cataract that had been removed by the time of testing.

The amblyopic subgroup consisted of 10 patients with deprivational amblyopia, 15 with strabismic amblyopia, 8 with anisometropic amblyopia, 8 with combined strabismic/anisometropic amblyopia, and 2 with lid hemangiomas. For some analyses, amblyopic patients were classified as either moderately amblyopic (0.4 to 0.6 logMAR, i.e., 20/40 to 20/80 in the affected eye; N = 35) or severely amblyopic (> 0.6 logMAR, i.e., $< 20/80$ in the affected eye; N = 8).

The nonamblyopic group was comprised of 20 children who had never had amblyopia and 10 children who had recovered from amblyopia with occlusion and/or atropine treatment.

To ensure that patients in the nonamblyopic subgroup did not have amblyopia, only those with normal optotype acuity in each eye as defined by age-appropriate norms were included in the study.¹⁷ Similarly, to ensure that amblyopic patients had unilateral amblyopia, only those with normal acuity in the fellow eye based on the same age-appropriate norms participated in the study.¹⁷

The research protocols followed the tenets of the Declaration of Helsinki, and was approved by the Institutional Review Board of the University of Texas Southwestern Medical Center. Informed written consent was obtained from the parents of participants following an explanation of the nature and possible consequences of the study.

Vernier Acuity Cards and Teller Acuity Cards

All participants were tested monocularly with the vernier acuity cards (see Figure 1), which were designed and developed at the Retina Foundation of the Southwest. The vernier acuity cards were modeled on the Teller Acuity Cards and an earlier vernier acuity card prototype created by Holmes and Archer.¹⁸ The test consists of twelve 25.5×55.5 cm

cards, each covered completely with high contrast (~ 95%), black and white stripes of a low spatial frequency (0.90 cpd). Each card has a misalignment in stripe position that forms a symmetrical second-order shape; a six-pointed star or a flower. The shape is located 13 cm to the left or right of a centrally located 3 mm peephole, and subtends a visual angle of 10.3° at the testing distance of 55 cm. Both second-order shapes are vertically and horizontally symmetrical so that the child was presented with the exact same shape when the cards were rotated 180°. Overall, the level of misalignment ranges from 29.8 to 0.43 min (1.47 to -0.37 log min) and progresses in 0.16 log min steps.

To assess grating acuity, all participants were tested monocularly with the Teller Acuity Cards II (TAC II; Stereo Optical Co Inc., Chicago, IL). The order of the testing was counterbalanced with vernier acuity card testing. For both grating acuity and vernier acuity, testing was conducted at a distance of 55 cm and followed an ascending two up/one down method of limits protocol for a total of 8 reversals.¹⁹ Detection of the stimulus in infants and toddlers was based on fixation preference whereas older children and adults were instructed to point at the stimulus. Both vernier acuity and grating acuity were calculated as the average of the last 6 reversals in logMAR units.

Optotype visual acuity was measured monocularly in each eye of all children in the patient cohort using an HOTV test²⁰ (N = 39) or a ETDRS test²¹ (N = 34). Both tests were presented electronically and use crowding bars positioned at a distance of either one-half letter width (HOTV) or one full letter width (ETDRS). Testing distance was 3 m, except in some cases of severe amblyopia in which it was necessary to conduct testing at 1.5 m. Optotype visual acuity testing was conducted prior to testing with Vernier Acuity Cards and Teller Acuity Cards.

Statistical Analyses

In the normative cohort, neither vernier acuity nor grating acuity was distributed normally (Kolmogorov-Smirnov test, $P < 0.01$). Therefore, to examine changes in vernier acuity and grating acuity with age, children were arranged in 1 year age bins and Kruskal-Wallis ANOVAs were conducted. Note that due to a limited number of participants, 10- to 13-year-old children and 14- to 17-year-old children were both grouped into single age bins. To determine when each visual function was mature, pairwise comparisons were conducted to compare younger age groups to adults. In addition, to describe the development of vernier acuity and grating acuity, a maximum likelihood procedure was used to fit a bilinear model of development.^{22–25}

In the patient cohort, each child's vernier acuity was classified as normal/abnormal based on the normative data. Specifically, a vernier acuity threshold was classified as abnormal if it fell outside of the range of vernier thresholds measured when testing the right eyes of age-matched normal children in the present study (presented in Table 1); vernier acuity thresholds that fell within the normal range were classified as normal. Each child's grating acuity was classified as normal/abnormal using age-appropriate norms gathered previously (See Table 1 in Drover et al.)²⁶

Because optotype acuity was not distributed normally in the patient cohort (Kolmogorov-Smirnov test, $P < 0.05$), Spearman rank correlation coefficients were calculated for all correlational analyses that included this measure. Both grating acuity and vernier acuity were distributed normally within the patient cohort so correlational analyses between these two variables were conducted using Pearson correlation coefficients. To compare the severity of grating acuity and vernier acuity deficits shown by children with amblyopia, a difference score was calculated by subtracting each child's grating acuity and vernier acuity score from the mean value of the corresponding test for age-matched, normal, children. An independent samples t-test was then conducted to compare these difference scores. To assess the clinical effectiveness of both grating acuity and vernier acuity, each participant's grating acuity and vernier acuity classification (i.e., normal/abnormal) was compared to his/her formal amblyopia diagnosis (i.e., based on optotype acuity). Sensitivity, specificity, and accuracy were calculated, along with 95% confidence intervals according to the efficient score method (corrected for continuity).

RESULTS

Normative Data

Grating acuity and vernier acuity for the normative cohort are plotted as a function of age in Figure 2. Note that these results are for right eyes only. For the youngest infants tested (0.2 to 0.5 years), both grating acuity and vernier acuity were markedly immature. Grating acuity was 0.96 logMAR (more than a factor of 8) lower than that of adults, whereas vernier acuity was even more immature at 1.29 logMAR (more than a factor of 16) poorer than that of adults. Also, vernier acuity of these infants was lower than grating acuity by 0.17 logMAR (about a factor of 1.5). As shown in Figure 2, vernier acuity did not surpass grating acuity until 5 years of age. As expected, both grating acuity and vernier acuity improved with age (both $P < 0.0001$). Pairwise comparisons indicated that participants' grating acuity did not differ from that of adults by 6 years of age ($P = 0.09$). Vernier acuity on the other hand, attained adult level at 8 years of age ($P = 0.45$).

A bi-linear model was fit to the raw data in order to characterize the maturational course for grating acuity and vernier acuity, using maximum likelihood analysis. In this model the inflection point is an index of the age at which mature visual function is achieved. The best-fit bilinear model for grating acuity had an inflection point at 5.4 years of age (Chi square = 296.94, $p < 0.001$). The maturation of vernier acuity was best described by a bilinear model with an inflection point at 6.2 years of age (Chi square = 337.34, $p < 0.001$), indicating rapid improvement until this age, and then reaching adult level at 8 years of age.

Vernier Acuity and Grating Acuity vs. Optotype Acuity in the Patient Cohort

Scatterplots illustrating the relationship between optotype acuity and grating acuity, and between optotype acuity and vernier acuity are shown in Figures 3A and 3B. Across all participants (i.e., amblyopic eyes and right eyes in nonamblyopic patients), both grating acuity and vernier acuity were correlated with optotype acuity (grating acuity: Spearman $r = 0.54$, $P < 0.001$; vernier acuity: Spearman $r = 0.60$, $P < 0.001$). In addition, grating acuity and vernier acuity were correlated (Pearson $r = 0.76$, $P < 0.001$). Across amblyopic eyes,

both grating acuity and vernier acuity were correlated with optotype acuity (grating acuity: Spearman $r = 0.34$, $P < 0.05$; vernier acuity: Spearman $r = 0.32$, $P < 0.05$). Once again, grating acuity and vernier acuity were correlated ($r = 0.66$, $p < 0.01$). For both vernier acuity and grating acuity, a large proportion of participants (both amblyopic and nonamblyopic) are plotted below the line of equivalence confirming that both of these visual functions are finer than optotype acuity.

Clinical/Screening Validity of the Vernier Acuity Cards and the Teller Acuity Cards

Summaries of patients' vernier acuity classification, grating acuity classification, and formal diagnoses are presented in Tables 2 and 3. Vernier Acuity yielded a sensitivity of 81% (95% CI: 66% to 91%) and a specificity of 73% (95% CI: 54 to 87%). Overall, the accuracy of the vernier acuity cards was 78% (95% CI: 69% to 88%). Grating acuity yielded a much lower sensitivity of 44% (95% CI: 29% to 60%) but comparable specificity of 93% (95% CI: 76% to 99%), and an accuracy of 64% (95% CI: 53% to 75%).

The sensitivity of both vernier acuity and grating acuity to all amblyopia subtypes and levels of severity is provided in Table 4. Vernier acuity yielded high sensitivity to all subtypes of amblyopia and levels of severity with the lone exception of anisometropic amblyopia (sensitivity = 63%). Interestingly, the vernier acuity cards were more sensitive than the TAC to all subtypes and levels of severity. It is important to note here however, these analyses should be considered preliminary due to the limited number of patients in each subtype/level of severity, which resulted in large 95% CIs for sensitivity.

The mean vernier acuity difference score (score relative to mean score for age-matched normal children) was significantly higher than the mean grating acuity difference score (0.29 logMAR v. 0.16 logMAR; $t_{42} = 4.11$; $P = 0.002$), suggesting that amblyopia had a greater detrimental effect on vernier acuity than on grating acuity.

DISCUSSION

Development of Vernier Acuity

The data presented here reveal that although vernier acuity is poorer than grating acuity early in life, it is a hyperacuity by approximately 6 years of age. This finding disagrees with those of earlier studies that suggest that vernier acuity surpasses grating acuity by 12 months of age. However, many of the earlier studies utilized a motion protocol in which the stimulus shifted from an aligned to a misaligned position.^{27, 28} Thus, misalignment and motion responses might have been confounded causing an overestimation of the rate of vernier acuity development.⁴ This explanation appears plausible as our data are in agreement with those of Skoczenski and Norcia,⁴ who in a well-controlled study, demonstrated that vernier acuity attains hyperacuity status at 6 years of age.

Our developmental data also indicate that although vernier acuity is markedly immature early in life, it reaches maturity at approximately 8 years of age. This developmental time course does not appear to correspond well with the development of the visual cortex, which reaches adult synaptic level in early adolescence.⁶ However, two important caveats must be stated here. First, the maturation of the visual cortex is not well understood and is based on

autopsy data collected by Huttenlocher and de Courten.⁶ There are large age gaps in these data. For instance, Huttenlocher and de Courten do not provide synaptic data for children between the ages of 5 and 11 years of age. Although one can conclude that maturity is attained by 11 years of age, it is possible that the visual cortex is mature at a much earlier age. Second, the true developmental time course of vernier acuity may have been masked by apparent ceiling effects in the present studies as children began to reach ceiling level ($-0.37 \log \text{ min}$) at approximately 8 years of age. It is possible that adult level of vernier acuity is much higher, and that vernier acuity continues to develop into later childhood or adolescence. In light of these caveats, one cannot conclude that the development of vernier acuity does not correspond with the maturation of the visual cortex.

Interestingly, the rate of maturation of vernier acuity reported here is more rapid than that found in most previous behavioral and electrophysiological studies (but see ref. 5).^{4, 7-9} In fact, Skoczinski and Norcia⁴ showed that vernier acuity continued to improve until approximately 14 years of age. The reason for this maturation discrepancy between studies is not clear, but may be due to the limited number of young children participating in the study. Specifically, for participants under the age of 6, only 8 – 13 children were tested per age bin. As such, these developmental data should be interpreted cautiously. Yet, it should be noted that our data generally agree with those of other studies that report that vernier acuity attains maturity later than grating acuity. Also, our results indicate that vernier acuity matures at a different rate than grating acuity and, therefore, it does not appear to be mediated by the retina.

Validity of Vernier Acuity

This is the first study to assess the validity of vernier acuity as tool for amblyopia detection. The results were promising as the new vernier acuity cards demonstrated good sensitivity to amblyopia. In fact the sensitivity of the vernier acuity cards was superior to that of the well-established TAC. In addition, our analyses indicate that compared to their grating acuity deficits, children with amblyopia demonstrated relatively severe vernier acuity deficits. These results imply that vernier acuity is more sensitive than grating acuity to cortical visual deficits. These results agree with those of other researchers who report that children with cortical visual impairment or cortical delays show severe vernier acuity deficits.^{11, 12}

One potential weakness in the comparison of sensitivities of vernier acuity and grating acuity is the use of slightly different criteria. Specifically, normal/abnormal classifications of vernier acuity were based on the normative range of scores because vernier acuity was not distributed normally. Normal/abnormal classifications of grating acuity were based on the 95% prediction interval for normative scores because these data were distributed normally. However if normal/abnormal classifications of grating acuity were also based on the normative range, both sensitivity and specificity for amblyopia are reduced because two false negatives and one false positive are added. Hence, the vernier acuity cards are still the superior tool for amblyopia detection.

Despite the superior sensitivity of the vernier acuity cards, our correlational analyses revealed two unexpected findings. First, the strength of the correlations between vernier acuity and optotype acuity, and grating acuity and optotype acuity for patients with

amblyopia were almost identical. A potential explanation for these similar correlations is apparent in Figures 3A and B. Specifically, compared to the vernier acuity data, grating acuity data in some instances is less “noisy”, with standard deviations in each age group about half as large as for vernier acuity. Thus, though the correlations are similar, a number of amblyopic patients score very poorly on vernier acuity, leading to higher variability but also higher sensitivity. Second, the correlation between grating acuity and vernier acuity (Pearson $r = 0.76$) was stronger than that between vernier acuity and optotype acuity (Spearman $r = 0.60$). This result conflicts with studies of adults that report that vernier acuity shows better agreement with optotype acuity than with grating acuity.^{1, 29} However, these results may reflect the procedural similarities between the TAC and vernier acuity cards, both of which are very different from the optotype acuity test used in the present study. Specifically, both the TAC and vernier acuity cards utilize a two-alternative forced choice protocol and testing is conducted at a distance of 55 cm.

Our preliminary analysis by subtype and level of severity indicates with the exception of anisometropic amblyopia, the vernier acuity cards yielded high sensitivity to all subtypes and level of severity. Compared to the TAC, the vernier acuity cards were more sensitive to all subtypes and levels of severity. Yet, we believe that these findings do not preclude vernier acuity as a tool to detect anisometropic amblyopia since children with this subtype show deficits in vernier acuity, but these deficits are proportionate to their losses in grating acuity.¹ In addition, we must again caution that these analyses are preliminary due to the low number of patients in amblyopia subtype/level of severity groups.

Although the sensitivity of the vernier acuity cards was impressive, specificity was lower at 73%. At first glance, this might imply that the vernier acuity cards should not be used in a screening setting because the false positive rate is high (27%). However, many of the false positives among our nonamblyopic patients had recovered normal optotype visual acuity following amblyopia treatment. If we limit the specificity analysis to only those nonamblyopic patients who were never treated for amblyopia ($N=20$), specificity improved to 85% (95% CI: 61 to 96%). In addition, the false positive rate may be inflated if some patients with amblyogenic risk factors were misclassified as nonamblyopic. In a screening setting, the vast majority of children do not possess amblyogenic risk factors and the false positive rate may be even lower.

One might question whether these results can be generalized to infants and toddlers. However, because there is no gold standard for this age group, it is not possible to determine whether a child truly has amblyopia. Thus, to evaluate a new test designed for infants and toddlers, one must assess children who can complete optotype acuity tests and therefore, be diagnosed formally as amblyopic/nonamblyopic.

Collectively, the results of the present study suggest that although it is not clear whether the developmental time course of vernier acuity corresponds with the maturation of the visual cortex, the vernier acuity cards were highly sensitive to amblyopia, a disorder that is cortical in nature. In fact, the validity of the vernier acuity cards was superior to that of the TAC, suggesting that this new test is an effective tool for detecting amblyopia.

ACKNOWLEDGMENTS

We thank the parents and children who participated in the study. This study was funded by the Thrasher Foundation, the National Eye Institute, the National Institute of Health (EY05236), the Dallas Stars Foundation, and the Pearle Vision Foundation. Portions of the data reported here were presented at the annual meeting of the American Association of Pediatric Ophthalmology and Strabismus, Washington, DC, April 2–6, 2008.

REFERENCES

1. Levi DM, Klein S. Differences in vernier discrimination for grating between strabismic and anisometropic amblyopes. *Invest Ophthalmol Vis Sci* 1982;23:398–407. [PubMed: 7107166]
2. Zanker J, Mohn G, Weber U, Zeitler-Driess K, Fahle M. The development of vernier acuity in human infants. *Vision Res* 1992;32:1557–64. [PubMed: 1455728]
3. Westheimer G. Do ocular-dominance columns set spatial limits for hyperacuity processing? *Vision Res* 1982;22:1349–52. [PubMed: 7157672]
4. Skoczenski AM, Norcia AM. Late maturation of visual hyperacuity. *Psychol Sci* 2002;13:537–41. [PubMed: 12430838]
5. Shapley R, Victor J. Hyperacuity in cat retinal ganglion cells. *Science* 1986;231:999–1002. [PubMed: 3945816]
6. Huttenlocher PR, de Courten C. The development of synapses in striate cortex of man. *Hum Neurobiol* 1987;6:1–9. [PubMed: 3583840]
7. Carkeet A, Levi DM, Manny RE. Development of Vernier acuity in childhood. *Optom Vis Sci* 1997;74:741–50. [PubMed: 9380372]
8. Kim E, Enoch JM, Fang MS, Lakshminarayanan V, Kono M, Strada E, Srinivasan R. Performance on the three-point Vernier alignment or acuity test as a function of age: measurement extended to ages 5 to 9 years. *Optom Vis Sci* 2000;77:492–5. [PubMed: 11014676]
9. Gonzalez EG, Steinbach MJ, Ono H, Rush-Smith N. Vernier acuity in monocular and binocular children. *Clin Vis Sci* 1992;7:257–61.
10. McKee SP, Levi DM, Movshon JA. The pattern of visual deficits in amblyopia. *J Vis* 2003;3:380–405. [PubMed: 12875634]
11. Skoczenski AM, Good WV. Vernier acuity is selectively affected in infants and children with cortical visual impairment. *Dev Med Child Neurol* 2004;46:526–32. [PubMed: 15287243]
12. Holmes JM. Comparison of grating and Vernier acuity in infants with developmental delay. *J Pediatr Ophthalmol Strabismus* 1996;33:31–4. [PubMed: 8965222]
13. Gstalder RJ, Green DG. Laser interferometric acuity in amblyopia. *J Pediatr Ophthalmol* 1971;8:251–6.
14. Cotter SA, Tarczy-Hornoch K, Song E, Lin J, Borchert M, Azen SP, Varma R. Fixation preference and visual acuity testing in a population-based cohort of preschool children with amblyopia risk factors. *Ophthalmology* 2009;116:145–53. [PubMed: 18962921]
15. Friedman DS, Katz J, Repka MX, Giordano L, Ibrionke J, Hawse P, Tielsch JM. Lack of concordance between fixation preference and HOTV optotype visual acuity in preschool children: the Baltimore Pediatric Eye Disease Study. *Ophthalmology* 2008;115:1796–9. [PubMed: 18538405]
16. Wright KW, Edelman PM, Walonker F, Yiu S. Reliability of fixation preference testing in diagnosing amblyopia. *Arch Ophthalmol* 1986;104:549–53. [PubMed: 3954659]
17. Drover JR, Felius J, Cheng CS, Morale SE, Wyatt L, Birch EE. Normative pediatric visual acuity using single surrounded HOTV optotypes on the Electronic Visual Acuity Tester following the Amblyopia Treatment Study protocol. *J AAPOS* 2008;12:145–9. [PubMed: 18155943]
18. Holmes JM, Archer SM. Vernier acuity cards: a practical method for measuring vernier acuity in infants. *J Pediatr Ophthalmol Strabismus* 1993;30:312–4. [PubMed: 8254447]
19. Birch EE, Hale LA. Criteria for monocular acuity deficit in infancy and early childhood. *Invest Ophthalmol Vis Sci* 1988;29:636–43. [PubMed: 3356518]
20. Moke PS, Turpin AH, Beck RW, Holmes JM, Repka MX, Birch EE, Hertle RW, Kraker RT, Miller JM, Johnson CA. Computerized method of visual acuity testing: adaptation of the amblyopia

- treatment study visual acuity testing protocol. *Am J Ophthalmol* 2001;132:903–9. [PubMed: 11730656]
21. Beck RW, Moke PS, Turpin AH, Ferris FL 3rd, SanGiovanni JP, Johnson CA, Birch EE, Chandler DL, Cox TA, Blair RC, Kraker RT. A computerized method of visual acuity testing: adaptation of the early treatment of diabetic retinopathy study testing protocol. *Am J Ophthalmol* 2003;135:194–205. [PubMed: 12566024]
 22. Owsley C, Knoblauch K, Katholi C. When does visual aging begin? *Invest Ophthalmol Vis Sci* 1992;33(Suppl.):1414.
 23. Birch EE, Cheng C, Stager DR Jr., Weakley DR Jr., Stager DR Sr. The critical period for surgical treatment of dense congenital bilateral cataracts. *J AAPOS* 2009;13:67–71. [PubMed: 19084444]
 24. Curcio CA, Millican CL, Allen KA, Kalina RE. Aging of the human photoreceptor mosaic: evidence for selective vulnerability of rods in central retina. *Invest Ophthalmol Vis Sci* 1993;34:3278–96. [PubMed: 8225863]
 25. Lachenmayr BJ, Kojetinsky S, Ostermaier N, Angstwurm K, Vivell PM, Schaumberger M. The different effects of aging on normal sensitivity in flicker and light-sense perimetry. *Invest Ophthalmol Vis Sci* 1994;35:2741–8. [PubMed: 8188467]
 26. Drover JR, Wyatt LM, Stager DR, Birch EE. The teller acuity cards are effective in detecting amblyopia. *Optom Vis Sci* 2009;86:755–9. [PubMed: 19390474]
 27. Shimojo S, Birch EE, Gwiazda J, Held R. Development of vernier acuity in infants. *Vision Res* 1984;24:721–8. [PubMed: 6464365]
 28. Shimojo S, Held R. Vernier acuity is less than grating acuity in 2- and 3-month-olds. *Vision Res* 1987;27:77–86. [PubMed: 3617548]
 29. Levi DM, Klein S. Hyperacuity and amblyopia. *Nature* 1982;298:268–70. [PubMed: 7088177]

Figure 1.
Photograph of the vernier acuity cards.

Figure 2.
Individual vernier acuity and grating acuity as a function of age.

Figure 3.

(A) Scatterplot representing the relationship between grating acuity and optotype acuity and (B) vernier acuity and optotype acuity. Diagonal line represents the line of equivalence.

Table 1.

Mean and range of vernier acuity in the right eyes of the normative cohort categorized by age group.

Age Group (years)	N	Mean (logMAR)	Range (logMAR)
Birth to 1 year	8	1.03	0.65 to 1.28
1	8	0.73	0.32 to 0.86
2	13	0.54	0.17 to 0.80
3	8	0.37	0.22 to 0.50
4	9	0.14	−0.14 to 0.43
5	12	−0.12	−0.35 to 0.14
6	15	−0.17	−0.35 to 0.04
7	17	−0.21	−0.32 to −0.09
8	14	−0.24	−0.37 to −0.09
9	9	−0.29	−0.37 to −0.13
10–13	13	−0.25	−0.37 to −0.13
14–17	16	−0.24	−0.37 to −0.13
18–35	18	−0.26	−0.37 to −0.13

Table 2.

Comparison of vernier acuity classification and formal amblyopia diagnosis.

Vernier Acuity	Optotype Acuity	
	Amblyopia	Not Amblyopic
Abnormal	35	8
Normal	8	22

Table 3.

Comparison of grating acuity classification and formal amblyopia diagnosis.

Grating Acuity	Optotype Acuity	
	Amblyopia	Not Amblyopic
Abnormal	18	2
Normal	23	27

Table 4.

Sensitivity of grating acuity and vernier acuity by amblyopia subtype/level of severity. Note that 95% confidence intervals are provided in parentheses.

Subtype (n)	Sensitivity	
	Vernier Acuity	Grating Acuity
Strabismic (15)	87 (62–96)	60 (36–80)
Anisometropic (8)	63 (30–86)	50 (22–78)
Mixed Strabismic/Anisometropic (8)	88 (53–98)	38 (14–69)
Deprivation (10)	90 (60–98)	40 (11–60)
Severity (n)	Vernier Acuity	Grating Acuity
Moderate (35)	80 (64–90)	43 (28–59)
Severe (8)	88 (53–98)	63 (30–86)