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The Teller Acuity Cards Are Effective in Detecting Amblyopia

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Abstract

Purpose—Detection of amblyopia in infants and toddlers is difficult because the current clinical standard for this age group, fixation preference, is inaccurate. Although grating acuity represents an alternative, studies of preschoolers and schoolchildren report that it is not equivalent to the gold standard optotype acuity. Here, we examine whether the Teller Acuity Cards (TAC) can detect amblyopia effectively by testing children old enough (7.8 ± 3.6 years) to complete optotype acuity testing.

Methods—Grating acuity was assessed monocularly in 45 patients with unilateral amblyopia, 44 patients at risk for amblyopia, and 37 children with no known vision disorders. Each child's grating acuity was classified as normal/abnormal based on age-appropriate norms. These classifications were compared with formal amblyopia diagnoses.

Results—Grating acuity was finer than optotype acuity among amblyopic eyes (medians: 0.28 vs. 0.40 logMAR, respectively, $p < 0.0001$) but not among fellow eyes (medians: 0.03 vs. 0.10 logMAR, respectively, $p = 0.36$). The optotype acuity-grating acuity discrepancy among amblyopic eyes was larger for cases of severe amblyopia than for moderate amblyopia (means: 0.64 vs. 0.18 logMAR, respectively, $p = 0.0001$). Nevertheless, most cases of amblyopia were detected successfully by the TAC, yielding a sensitivity of 80%. Furthermore, grating acuity was relatively sensitive to all amblyopia subtypes (69 to 89%) and levels of severity (79 to 83%).

Conclusions—Although grating acuity is finer than optotype acuity in amblyopic eyes, most children with amblyopia were identified correctly suggesting that grating acuity is an effective clinical alternative for detecting amblyopia.

Keywords

infant; vision; amblyopia; visual acuity; grating acuity

Clinical diagnosis of unilateral amblyopia in infants and toddlers is challenging because the current clinical standard, fixation preference testing, is inaccurate. Specifically, it yields a high false-negative rate (60 to 80%) for cases of amblyopia with small tropias or orthotropia,^{1,2} and a high false-positive rate (31 to 68%) for cases of large angle strabismus.^{1,2} Grating acuity represents an alternative as it possesses merits that make it suitable for testing infants and toddlers. Indeed, the most widely used behavioral assessment test of grating acuity, using the Teller Acuity Cards (TAC), yields good reliability,^{3,4} can be completed by most infants and

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toddlers,^{5,6} and has been successful in assessing children with a variety of visual and developmental disorders.^{7–9}

Despite these merits, prior studies of infants and toddlers report that grating acuity yields only poor to moderate sensitivity (sensitivity = 29 to 68%) to amblyopia.^{10–12} However, patients in these studies were diagnosed based on fixation preference, which as noted earlier, is now considered inaccurate. To evaluate the clinical effectiveness of grating acuity then, it is necessary to assess children old enough to complete gold standard optotype acuity tests.¹³ Still, studies of older children reveal that grating acuity and optotype acuity estimates are not equivalent in children with amblyopia. Estimates of grating acuity are finer (but see ref. ¹⁴), ^{10,13,15–17} and the discrepancy between the measures is greater with increasing severity of the visual deficit.^{10,13,15,17} Thus, it is not surprising that studies of preschool and school-aged children report that grating acuity is insensitive to amblyopia (sensitivity = 15 to 50%).^{10,13} Yet, these studies are limited by inadequate diagnostic criteria for grating acuity. For instance, Kushner et al.¹³ used the equivalent diagnostic criteria for optotype acuity and grating acuity ($\leq 20/40$) even though normative data differ for the two tests. Other researchers used a fixed interocular difference (IOD) in grating acuity as the sole measure to detect amblyopia even though IOD has considerably higher variability than monocular grating acuity.¹¹ Thus, it remains possible that children with amblyopia demonstrate substantial grating acuity deficits that can be identified by using diagnostic criteria based on age-appropriate grating acuity norms.

In this study, we evaluate the clinical effectiveness of grating acuity estimates in detecting amblyopia among preschool and school-aged children. We assessed grating acuity and optotype acuity in patients with unilateral amblyopia, patients at risk for amblyopia, and children with no known vision disorders. Each child's grating acuity was compared with his/her formal amblyopia diagnoses.

METHODS

Participants

Participants included a convenience sample of 126 children (mean age = 7.8 years, SD = 3.6 years) participating in ongoing studies that included grating and optotype acuity assessment as part of the testing protocol. The research protocols for these studies followed the tenets of the Declaration of Helsinki and were 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 studies. Participants were from one of three groups: (1) children with unilateral amblyopia ($n = 45$; mean age = 7.1 years, SD = 3.4 years); (2) children at risk for amblyopia, with unilateral amblyogenic factors (strabismus, cataract, or anisometropia) but not amblyopic at the time of testing ($n = 44$ mean age = 8.1 years; SD = 4.4 years); (3) children with no known vision disorders ($n = 37$; mean age = 8.1 years; SD = 2.4 years).

Formal diagnoses of amblyopia were based on a ≥ 0.2 logMAR (two-line) interocular difference on optotype 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 ($\geq 1D$), or a unilateral cataract that had been removed by the time of testing.

The amblyopic group consisted of 14 patients with deprivational amblyopia, 9 with strabismic amblyopia, 13 with anisometropic amblyopia, and 9 with combined strabismic/anisometropic amblyopia. For some analyses, amblyopic patients were classified as either moderately amblyopic (0.3–0.6 logMAR, i.e., 20/40 to 20/80 in the affected eye; $n = 39$) or severely amblyopic (>0.6 logMAR, i.e., $<20/80$ in the affected eye; $n = 6$).

To ensure that patients in the at-risk group did not have amblyopia and that children with no known vision disorders had normal vision, only those with normal optotype acuity in each eye as defined by age-appropriate norms¹⁸ were included in the study. Similarly, to ensure that amblyopic patients had unilateral amblyopia, only those with normal acuity in the fellow eye based on the age-appropriate norms¹⁸ participated in the study.

Procedure

All vision testing was conducted while the child was wearing his/her best optical correction. Grating acuity was assessed monocularly using the Teller Acuity Cards II (Stereo Optical, Chicago, IL) at a distance of 55 cm. For all participants, testing began with the presentation of the 2.4 cyc/cm card and proceeded following a two down-one up staircase protocol for a total of eight reversals.¹⁹ Visual acuity was calculated as the average of the last six reversals and converted from spatial frequency (i.e., cy/deg) to logMAR units [$\log\text{MAR} = -1 \times \log(\text{spatial frequency}/30)$].

Optotype visual acuity was measured monocularly in each eye of all children using a crowded [HOTV (n = 55), ETDRS (n = 26)] or linear optotype acuity test [ETDRS (n = 35), Lea Symbols (n = 1), Snellen (n = 9)]. The E-ETDRS, HOTV, and Lea Symbols acuity tests followed logMAR format, whereas the Snellen visual acuity test followed the traditional visual acuity format. Testing distance was 3 m, except in some cases of severe amblyopia in which testing was conducted at 1.5 m. Each child's grating acuity was classified as normal/abnormal according to criteria derived from normative data published by Mayer et al.³ (for 3- and 4-year-olds) and from ongoing studies conducted at the Retina Foundation of the Southwest (≥ 5 years of age). These data are presented in Table 1. Specifically, normal/abnormal classifications were based on the lower limit of the 95% tolerance interval, which was defined as 1.96 standard deviations below the mean for each age group. Children who scored below the lower limit (i.e., below the lower limits presented in Table 1) were classified as having abnormal grating acuity. Those who scored above the lower limit (i.e., above the lower limits presented in Table 1) were classified as having normal grating acuity.

Analyses

Because optotype acuity and optotype acuity IOD were not distributed normally (Kolmogorov-Smirnov test, $p < 0.05$), these data were analyzed using nonparametric tests. Wilcoxon matched pairs tests were conducted to compare grating acuity and optotype acuity in both amblyopic eyes and fellow eyes of patients with amblyopia. Spearman rank correlation coefficients were calculated for grating and optotype acuity and for grating and optotype acuity IOD. Optotype acuity-grating acuity differences were distributed normally and were analyzed using one-way ANOVAs. To assess the clinical effectiveness of grating acuity, each participant's grating acuity classification (i.e., normal/abnormal) was compared with his/her formal amblyopia diagnosis (i.e., based on optotype acuity). Sensitivity, specificity, and accuracy were calculated.

RESULTS

Grating Acuity vs. Optotype Acuity

Among amblyopic eyes, grating acuity was finer than optotype acuity (medians: 0.28 vs. 0.40 logMAR, respectively, $p < 0.0001$). Fellow eyes of patients with amblyopia did not differ (medians: TAC = 0.03 logMAR, Optotype = 0.10 logMAR, $p = 0.36$). A Bland-Altman plot illustrating the difference between the two measures among amblyopic eyes is presented in Fig. 1. The figure indicates that, for the most part, the mean optotype acuity-grating acuity discrepancy was smaller for cases of moderate amblyopia than for severe cases (0.18 vs. 0.64 logMAR, respectively; mean difference = 0.46 logMAR, 95% CI: 0.30 to 0.62 logMAR, $p =$

0.0001). A preliminary analysis revealed that the optotype acuity-grating acuity discrepancy was similar across amblyopia subtype (strabismic = 0.37 logMAR; anisometropic = 0.18 logMAR; combined strabismic/anisometropic = 0.37 logMAR; deprivational = 0.24 logMAR; $p = 0.35$).

A scatterplot illustrating the relationship between grating and optotype acuity is provided in Fig. 2. Across all children (i.e., amblyopic eyes and right eyes in at-risk patients and children with no disorders), there was a significant correlation between the two measures ($r = 0.67$, $p = 0.0001$). Unlike at-risk patients and children with no disorders, however, a large proportion of children with amblyopia are plotted below the line of equivalence, confirming that grating acuity was finer than optotype acuity. Furthermore, although there was a trend toward significance, grating acuity and optotype acuity of amblyopic eyes were not correlated ($r = 0.25$, $p = 0.10$). However, grating acuity IOD and optotype acuity IOD were correlated in children with amblyopia ($r = 0.41$, $p = 0.007$).

Clinical Effectiveness of the Teller Acuity Cards

Comparison of participants' grating acuity classification and formal amblyopia diagnosis is presented in Table 2. Grating acuity yielded a sensitivity of 80% (95% CI: 68 to 92%) and a specificity of 74% (95% CI: 65 to 84%). Overall, the accuracy of grating acuity was 76% (95% CI: 69 to 84%), indicating that 96/126 grating acuity classifications (normal/abnormal) were correct.

The clinical effectiveness of grating acuity was relatively high across amblyopia subtypes and levels of severity. Specifically, grating acuity yielded high sensitivity to strabismic, deprivational, and combined strabismic/anisometropic amblyopia (sensitivity = 78, 86, and 89%, respectively). Sensitivity to anisometropic amblyopia was lower at 69%. Finally, grating acuity yielded a sensitivity of 79% to moderate amblyopia and 83% to severe amblyopia. Note that these analyses should be considered preliminary due to the limited number of patients in each subtype/level of severity.

DISCUSSION

As in other studies, the results of this study demonstrate that among amblyopic eyes, grating acuity tests provided finer estimates of visual acuity than optotype acuity tests,^{10,13,15–17} and the difference between the measures was greater with increasing severity of amblyopia.^{10,13,15,17} The disagreement between estimates of grating and optotype acuity is well documented and has been attributed to differences in the nature of the two tests, including differences in testing distance,¹³ size of the visual targets,¹⁶ and difficulty of the tasks.¹³ Yet, if these explanations were correct, a significant optotype acuity–grating acuity discrepancy should have been found for fellow eyes. This was not the case (medians: TAC = 0.03 logMAR, optotype = 0.10 logMAR). However, we must point out that the lack of a discrepancy might be due to ceiling effects as children could score no better than -0.10 logMAR (38 cy/deg) on the TAC at a testing distance of 55 cm. The potential for a ceiling effect could have been minimized by testing children at the furthest distance recommended by the manufacturer (i.e., 84 cm).

It is likely that the underlying mechanism for the optotype-grating acuity discrepancy is more complex. McKee²⁰ and Levi and Klein²¹ posit that the acuity differences might be related to deficits in binocular function and that patients who lack binocular function exhibit larger optotype acuity-grating acuity differences than those who do not. Specifically, Levi and Klein²¹ suggest that the weaker eye of a child with no binocular function possesses adequate neuronal representation tuned to moderate spatial frequencies to facilitate the detection of gratings near his/her cut-off spatial frequency. However, there is a lack of cortical neurons

driven by the central visual field of the amblyopic eye leading to undersampling, and as a result, failure to achieve a true representation of local spatial relationships, a requirement for optotype identification. Thus, the child cannot identify optotypes near his/her cut-off spatial frequency. In children with binocular function, the eyes share a number of neurons in the primary visual cortex that are tuned to all suprathreshold spatial frequencies. Although these neurons are maintained primarily by stimulation of the stronger eye, this stimulation ensures adequate coverage of the central visual field of both eyes. Therefore, undersampling is avoided in the weaker eye along with the deleterious effects on optotype acuity.

In this study, 31 amblyopic patients and 18 at-risk patients completed stereopsis testing with Randot Preschool Stereoacuity Test.²² Seven amblyopic patients and 11 at-risk patients had measurable stereopsis (≤ 800 arc sec). These patients had smaller optotype acuity-grating acuity differences in their weaker eye than children who did not have measurable stereopsis (medians: 0.10 vs. 0.25 logMAR; Mann Whitney U test, $p < 0.02$). This result supports the hypothesis of McKee and Levi and Klein.

The primary purpose of this study was to evaluate the clinical potential of grating acuity as a tool to detect amblyopia. Previous studies were limited as they did not account for the tendency of grating acuity tests to provide finer estimates than optotype acuity tests, negating the use of equivalent optotype acuity/grating acuity criteria.¹³ Alternatively, another study used a criterion based solely on IOD which is more variable than monocular grating acuity and therefore inadequate as a diagnostic criterion.¹¹ In fact, the data of this study were reanalyzed using the standard IOD criterion of ≥ 1 octave. This reanalysis revealed that although specificity was very high at 98%, sensitivity was extremely poor at 30%. In fact, the use of the IOD criterion did not lead to the detection of a single case of amblyopia that was not detected using criteria based on the age-appropriate grating acuity norms.

Following age-appropriate grating acuity criteria, grating acuity yielded a sensitivity of 80%, much higher than reported previously (15 to 50%).^{10,13} Although our findings confirm that children with amblyopia possess finer grating acuity than optotype acuity, the majority scored below age-appropriate norms and were identified correctly. Moreover, a preliminary analysis indicated that with the lone exception of anisometropic amblyopia, sensitivity was high across all amblyopia subtypes and levels of severity. This result contrasts with those from other studies that found robust differences between grating and optotype acuity in cases of strabismic amblyopia,^{11,23,24} implying poor sensitivity to this subtype. The slightly lower sensitivity of grating acuity to anisometropic amblyopia is perplexing given that previous studies report relatively small grating acuity-optotype acuity discrepancies.^{23,24} Nevertheless, we must point out that the sensitivity of grating acuity to anisometropic amblyopia reported here (69%) is still far superior than that yielded by fixation preference testing (20%).²

Specificity of the TAC under the present criteria was 74%, lower than reported previously (91%).¹³ However, we believe that this specificity is acceptable for a clinical test. If a child is diagnosed incorrectly with amblyopia, treatment would likely consist of a 2 to 3 months of part-time monocular occlusion and would be unlikely to cause adverse effects on functional vision.

Although our findings suggest that grating acuity is effective at detecting amblyopia, three caveats must be noted. First, one might question whether these results can be generalized to infants and toddlers. However, because there is no gold standard for infants and toddlers, it is not possible to determine whether a child truly has amblyopia. Thus, as Kushner et al.¹³ point out, to evaluate the clinical effectiveness of grating acuity, one must assess children who can complete optotype acuity tests. Second, although grating acuity is suitable for clinical detection of amblyopia, it is not appropriate for general vision screening because it yields a false-positive

rate of 26%. Third, the grating acuity criteria provided in this study allow categorical judgments of vision only (i.e., normal/abnormal vision) and therefore, will not be effective in monitoring acuity changes in the amblyopic eye during treatment until acuity is within normal range. Yet, it is possible to monitor these changes by measuring the difference between the patient's acuity and the normal cutoff. However, this may be too complicated for clinicians to use routinely. Despite these caveats, the results presented here indicate that when appropriate diagnostic criteria are implemented, grating acuity possesses good clinical effectiveness as the majority of children with amblyopia are identified. Thus, we believe that grating acuity is suitable to be used as a substitute for, or in conjunction with fixation preference testing when assessing infants, toddlers, and older children who are unable to complete optotype acuity tests.

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FIGURE 1.

Bland-Altman plot of optotype acuity–grating acuity. The solid line represents mean optotype acuity–grating acuity difference, whereas dashed lines represent 95% confidence limits.

FIGURE 2.

Scatterplot representing the relationship between grating acuity and optotype acuity in all participants. Diagonal line represents the line of equivalence.

TABLE 1

Mean grating acuity and lower limit categorized by age group

Age group (years)	Mean teller acuity (logMAR)	Mean acuity (Snellen equivalent)	Lower limit (logMAR)	Lower limit (Snellen equivalent)
3	0.15	20/28	≥ 0.33	$\leq 20/43$
4	0.08	20/24	≥ 0.24	$\leq 20/35$
5	-0.01	20/20	≥ 0.12	$\leq 20/26$
6	-0.03	20/19	≥ 0.08	$\leq 20/24$
7	-0.05	20/18	≥ 0.08	$\leq 20/24$
8-10	-0.05	20/18	≥ 0.08	$\leq 20/24$
11-18	-0.06	20/17	≥ 0.07	$\leq 20/23$

These data are gathered from Mayer et al.³ and from ongoing studies at the Retina Foundation of the Southwest. The lower limits presented here were used to classify children in this study as having normal/abnormal vision.

TABLE 2

Comparison of grating acuity classification and formal amblyopia diagnosis

Grating acuity	Optotype acuity	
	Amblyopia	Not amblyopic
Abnormal	36	21
Normal	9	60