Grating and recognition acuities of young amblyopes

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SUMMARY The visual acuities of 36 young amblyopes were determined by (a) conventional recognition tests (near and distance) and (b) an adapted grating acuity card procedure. Considerable agreement between the estimates of acuity obtained with each method was demonstrated, which was generally less than, or equal to, the mean difference between adjacent Snellen lines (4.5 c deg^{-1}). Estimates of grating acuity obtained with vertical gratings did not differ significantly from those obtained with horizontal gratings. There was no difference between the subjects' ability to detect the grating (acuity) and accurately to discriminate target orientation (horizontal or vertical). The results of the experiment are discussed in relation to previous findings of a discrepancy between grating and recognition acuities in amblyopia, and the clinical use of the acuity card procedure.

The observation that infants will preferentially fixate a patterned rather than a 'blank' or homogeneous surface¹ has spawned a variety of behavioural tests of infant visual acuity. Procedures such as forced-choice preferential looking (FPL) and operant preferential looking (OPL) have been used to study normal visual development²⁻⁷ and abnormalities of vision in infants and young children.⁸⁻¹¹ The assessment of visual acuity by preferential looking procedures typically involves the simultaneous presentation of a grating pattern and a homogeneous field of equal space-average luminance. An observer, who is unaware of the position of the stimulus, judges from the infant's looking behaviour whether the grating has been detected. The observer's responses are used to generate a psychometric function from which an estimate of the infant's visual acuity can be obtained. With identical grating targets these procedures can be adapted for use with older children, target detection being signalled by pointing or verbal identification.

Vision tests based on preferential looking have until recently been restricted to laboratory use and have not been employed for routine clinical assessment. The often sophisticated nature of the apparatus required to present the grating stimuli and the need to present a large number of trials to obtain a reliable measure of acuity have limited their clinical application. Recently, however, a new 'acuity card

procedure'¹² has been developed which may be particularly suitable for routine orthoptic or ophthalmological use. Acuity cards are photographically reproduced square-wave gratings mounted in cardboard frames. The experimenter determines the visual acuity by observing the highest spatial frequency target to which a behavioural response (for example, pointing, eye, and head movements) is elicited. Lengthy psychophysical procedures are not involved. Despite its apparent lack of sophistication the acuity card procedure yields acuity age norms equivalent to those obtained with other more complex forced choice methods and has small inter-observer test-retest differences¹³ (Dobson V, Schwartz TL, personal communication).

The assessment of vision with grating targets may be a particularly suitable means of monitoring visual function in young amblyopes undergoing therapy. The use of standard recognition tasks is often inappropriate with an uncooperative, shy, or poorly motivated child or for one who is unable to respond to conventional optotypes. However, there is some evidence to suggest that grating acuities may considerably overestimate recognition acuities in amblyopia; that is, normal grating acuities (6/6 Snellen equivalents) can be recorded in subjects whose recognition acuities are markedly impaired.¹⁴ One explanation for this finding is the spatial distortion of vision reported in amblyopia¹⁵ that would be expected to differentially impair recognition acuity. If the disparity between recognition and grating acuities is consistently large, it may be inappropriate to assess amblyopic vision with grating targets.

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Previous use of the acuity card procedure has been restricted to neonates and infants (typically less than 3 years old). In this study we evaluate the use of an adapted acuity card procedure in an older group of amblyopic children and compare their grating acuities with those obtained by conventional recognition tests.

Materials and method

Thirty-six children ranging in age from 4.4 to 9.3 years (mean 6.3 years) were recruited for the experiment and were all attending the Orthoptic Department at the Leicester Royal Infirmary. The diagnostic categories of amblyopia in which they were placed were strabismic (17), anisometropic (6), and anisometropic and strabismic (13). The experiment was performed after a review of their orthoptic treatment. Near and distance recognition acuities were measured before and after the determination of grating acuity by a method appropriate to their age and developmental status (Table 1). Grating acuities were measured by an adapted acuity card procedure in which grating targets paired with a 'blank' field of equal space-average luminance were presented within a rectangular aperture in a cardboard surround (Fig. 1). Trials were administered according to a descending method of limits which involved the repetition of each grating three times with position (left, right) randomised. Ten spatial frequencies were tested ranging from 3 c deg^{-1} (6/60) to 30 c deg^{-1} (6/6). Full details of the grating targets are given in Table 1. Testing was terminated at the highest spatial frequency at which three 'don't know' responses were elicited. Subjects were encouraged not to guess.

A total of three grating conditions were presented in a balanced and randomised experimental design. The first two conditions consisted of a simple detection task of gratings which were either vertically (condition 1) or horizontally (condition 2) orientated. In the third condition both horizontal and vertical gratings were presented, and in addition to detecting the presence of the grating subjects were

Fig. 1 The acuity card apparatus: surround and stimulus cards. (After McDonald et al.¹²)

required to indicate its orientation. A variety of behavioural responses were elicited which most commonly included pointing combined with a verbal response. The orientation discrimination task (condition 3) was included because, during clinical use of the acuity card procedure by one of us (ARF), it had been observed that in some cases a considerable disparity existed between a detection threshold (acuity) and the ability to distinguish accurately the orientation of the grating. All acuity measurements were obtained in the amblyopic eye only, with spectacle correction (if prescribed) worn.

Results

Grating acuities (pooled across horizontal and vertical orientation) were estimated by a logistic

Table 1 Details of grating and recognition acuity tasks

Recognition acuity		Grating acuity
Near : (0-33 m)	Distance (6 m)	
RAF rule (24)	Snellen: linear optotype (25)	Grating targets subtended, 3-0, 4-0, 6-0, 7-5, 10-0, 12-0, 15-0, 20-0, 24-0, and 30 c deg ⁻¹ at 0-36 m
'Matching' RAF rule (8)	'Matching' Snellen: linear optotype (18)	Acuity cards were back-illuminated with a single tungsten filament light source. Space-average luminance of targets and 'blank' field was approximately 1.3 log cd m ⁻²
Reduced linear Snellen (4)	Sheridan Gardiner: single optotype (3)	
Number of children tested shown in parentheses

Fig. 2 Relationship between near recognition acuity and grating acuity.

model as described in the Appendix. Near and distance recognition acuity were defined as the arithmetic mean of the scores obtained before and after the determination of grating acuity.

The relationship between grating and recognition acuities (near and distance) are shown in Figs. 2 and 3. The 'line of equality' corresponds to the points at which grating and recognition acuities are in perfect

Fig. 3 Relationship between distance recognition acuity and grating acuity.

Fig. 4 Difference between grating acuity and near recognition acuity against mean acuity.

agreement. Grating acuity was shown to be significantly correlated with recognition acuity (near: $r=0.33$, $p<0.05$; distance: $r=0.55$, $p<0.001$).

Although both near and distance recognition acuities are significantly correlated with grating acuity, this finding does not indicate the extent of the agreement between the two measures. The difference between agreement and correlation can be appreciated by inspection of the scattergrams shown in Figs. 2 and 3. Measures of recognition and grating acuity scores are in exact agreement only when they lie on the 'line of equality'. However, a high positive correlation would be obtained if the data points formed any straight line with a positive slope. For a further discussion on the inappropriate use of the correlation coefficient when estimating the agreement between two alternative measures the reader is referred to the recent paper by Bland and Altman.¹⁶ The extent of the agreement between grating and recognition acuities is shown in Figs. 4 and 5. The data points show for each child the difference between the grating and recognition acuities plotted against the mean acuity (grating+recognition/2). Perfect agreement is indicated by points falling on the 'zero difference line'—agreement decreasing as a function of the distance between this line and each data point.

The final analysis compared the grating detection thresholds (acuity) with the thresholds obtained for correctly discriminating the orientation of the grating targets (see 'Materials and methods'). A χ^2 test of the change in the log likelihood (see Appendix) failed to reveal any difference between the subjects' ability to detect or discriminate the orientation of the gratings.

Fig. 5 Difference between grating acuity and distance recognition acuity against mean acuity.

Similarly, there were no differences in the grating acuities obtained with horizontal or vertical gratings.

Discussion

If the acuity card procedure is to prove a viable method of routinely assessing visual acuity in amblyopes it must fulfil two criteria. Firstly, grating acuities must relate in some predictable manner to those obtained with conventional methods. Secondly, the ease and length of time taken to administer the test must be in accord with the constraints imposed by clinical use.

The extent of the agreement between grating and recognition acuities is shown in Figs. 4 and 5. Adopting a bandwidth of 4.5 c deg^{-1} (this corresponds to the mean difference between adjacent lines on a standard Snellen chart in the range 6/6 to 6/60) we can see that 24(67%) of the differences between the grating and recognition acuities against the mean acuities fall on or within this bandwidth for near recognition and 28(78%) for distance recognition. Apart from cases in which distance acuity was determined from single optotype characters, the proportion of scores that fall within the 4.5 c deg^{-1} bandwidth rises to 82%—that is, the grating and recognition acuities of 27 out of 33 subjects agreed within one mean Snellen line (single optotypes will frequently overestimate recognition acuity owing to the 'crowding effect' or contour interaction that occurs with line optotypes).^{17,18} Doubling this bandwidth to 9 c deg^{-1} that is, twice the mean difference

between adjacent Snellen lines, leaves 32(89%) of near recognition acuities and 34(94%) of distance recognition acuities within this bandwidth. These findings show that grating acuities can provide clinically useful estimates of visual acuity which are, in most cases, in good agreement with those obtained by conventional methods.

The results failed to reveal any differences between grating detection thresholds (acuity) and the threshold for correctly discriminating grating orientation. It had been supposed from our previous clinical experience that the orientation discrimination task would prove more difficult. Careful attention was paid to matching the luminance of each grating target with that of the corresponding 'blank' by back-illuminating the acuity cards. Failure to do this could have resulted in the child responding to the brightest aperture in the test card, thus producing a spurious estimate of acuity. Our experience suggests that equating the luminance of the grating targets with the 'blank' field is an important prerequisite for the efficient administration of the acuity card procedure. Incorporating an orientation discrimination task into the acuity card procedure may be one safeguard to prevent subjects from responding to differences in luminance when presented with a subthreshold grating target.

Our results do not confirm previous findings^{10,14} that grating acuities will significantly overestimate recognition acuity—none of our sample of amblyopic children was found to possess a normal grating acuity i.e. 30 c.deg^{-1} . However, the threshold criterion for grating acuity (probability of correct detection = 95%, see Appendix) was deliberately set to a high level. This ensured that grating acuity was appropriately equated with the high level of certainty with which the recognition acuities were obtained in this study and indeed in standard clinical practice. Using a slightly less rigorous (80%) criterion, Jenkins and co-workers¹⁹ have also demonstrated the predictive value of grating acuity in the assessment of amblyopic vision. In clinical practice however, the subjective method of analysis of the acuity card procedure may increase the likelihood of grating acuities exceeding those obtained with a recognition task.

In this study grating acuities were determined by two orthoptists with considerable experience in measuring visual acuity in young children. In their opinion the adapted acuity card procedure was easy to administer, and frequently a more rapid response was elicited from the child presented with the acuity cards than when presented with a recognition target. The test procedure for determining grating acuities in the present experiment differed from that originally described. Here, acuities were obtained with a

descending method of limits in order that the possible differences in thresholds for gratings of different orientations could be accurately determined. (In the original version of the test the examiner is free to choose which gratings to present and the estimate of acuity is based on their subjective opinion of the infant's behaviour.) This adaptation inevitably increased the time taken to administer the test, though it was apparent that, had the original acuity card procedure been adhered to, an estimate of acuity could have been obtained in 2 to 3 minutes.

APPENDIX

The modified logistic model

The usual logistic model for analysing binary data assumes that there exists a threshold above which the subject's response is correct and below which it is incorrect. When performing the experiment the examiners noticed that despite counter instruction many of the children appeared to guess the position of the grating, an observation supported by the number of incorrect replies given. To allow for this in the analysis the logistic model was modified to allow for three responses, namely 'correct', 'incorrect', and 'don't know'.

The modified logistic model assumes that there exist thresholds q_0 and q_1 . Below q_0 the response is 'correct', between the two the subject guesses and thus has an equal chance of being 'correct' or 'incorrect', and above q_1 the response is 'don't know'.

If F represents the distribution function of the logistic distribution the probabilities of the three possible responses may be expressed as,

$$\begin{aligned}\text{Prob. (correct)} &= 1/2 [F(q_1 - by) + F(q_0 - by)], \\ \text{Prob. (incorrect)} &= 1/2 [F(q_1 - by) - F(q_0 - by)], \\ \text{Prob. (don't know)} &= 1 - F(q_1 - by),\end{aligned}$$

where y is the size of the grating under test and b is a scale parameter.

The parameters q_0 , q_1 , and b were estimated by the method of maximum likelihood, and the grating acuity y_0 of the subject was defined as that grating that they would have correctly located on 95% of tests. That is to say,

$$1/2 [F(q_1 - by_0) + F(q_0 - by_0)] = 0.95.$$

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