Cross-optotype metrics for foveal lateral masking

Sarah J. Waugh[1], Monika A. Formankiewicz[1], Denis G. Pelli[2]

[1] Anglia Vision Research, Vision and Hearing Sciences, Anglia Ruskin University, Cambridge, U.K. [2] Psychology Department, New York University, U.S.A.

Introduction

Clinically, visual acuity is assessed with a chart full of letters spaced 1 letter-width apart. For children, a single letter is surrounded by 4 others (Cambridge Crowding Cards), a line of letters is surrounded by a box, or a single letter is surrounded by a box or bars. In commercially-available tests, surrounds are placed 0.5 to 1 optotype-width (OW) away from the target. For very young children pictures or symbols are used, instead of letters. For screening it's desirable to have measures of visual acuity and lateral masking that are conserved across the symbol, picture and letter optotypes. Recent work (Formankiewicz & Waugh, 2013; Song, Levi & Pelli, 2014; Lalor et al, 2016) showed that optotypes should be placed closer than 0.5 OW, but it is not clear what separation metric provides best consistency of lateral masking across optotype.

Separation Metrics

Research studies have used stroke-widths, specified edge-to-edge (SW-EE) (Formankiewicz & Waugh, 2014; Lalor et al, 2016); arcmin, specified edge-to-edge (arcmin-EE) (Siderov et al, 2013); and optotype-widths specified centre-to-centre (OW-CC) (Song, Levi & Pelli, 2014). We compare these units for consistency of lateral masking across pictures, symbols and letters.

Optotypes and Arrangements

Optotypes with very different size:stroke ratios are used (see Figure 1): HOTV, a subset of Sloan letters (5:1), Kay Pictures, U.K. commercially available picture optotypes (10:1) and Lea Symbols, commercially available symbol optotypes (7:1). Single optotypes were isolated, or surrounded by a box, bars or 4 similar optotypes in a Cambridge Crowding Card arrangement.

Questions

1. Does a target surrounded by pictures or symbols produce similar effects to letters?
2. How do these relate to the effects of bars or a box?
3. Is any masking metric conserved across different size:stroke ratios?

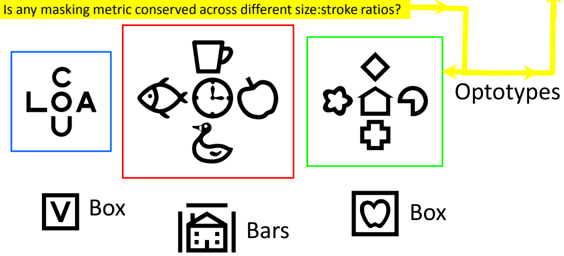

Figure 1: Examples of HOTV target letters (left), Kay Pictures (middle) and Lea Symbols (right) in Cambridge Crowding format (top) and surrounded by a box or bars (bottom).

Methods

Laboratory Experiments

Three healthy adults with good corrected vision and stereopsis (60" TNO test) participated. Visual acuity was measured for isolated and flanked optotypes at separations of 0, 1, 2, 3, 4, 5, 8 and 10 SW-EE. Percent correct performance was calculated across 7 levels of optotype size using a method of constant stimuli and a 4AFC response paradigm. Data were averaged and fit with a psychometric (Weibull) function. A repeated measures ANOVA (with Huynh-Feldt correction) was applied to acuity, threshold-elevation and psychometric function slopes.

Clinical Staircases

Sixteen healthy adults with good corrected vision and stereopsis (60" TNO test) participated. Visual acuity was measured using a 2-down, 1-up staircase combined with a 4AFC response paradigm. Staircases for flanker type (box, bars, optotype) and separation condition (isolated target and 1 arcmin-EE, 1 SW-EE, 1.2 OW-CC separations) were randomised. Staircases were repeated on a separate occasion and results averaged.

Optotype x Metric

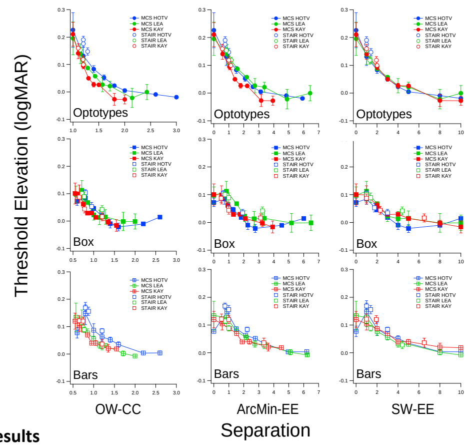

Figure 2: Lateral masking functions. Visual acuity (logMAR) for an isolated optotype is subtracted from acuity with a surround to give threshold elevation (Y axis). Separation of surround (X axis) is plotted in three different units OW C-C (left), arcmin E-E (middle), SW E-E (right). Surrounds are optotypes (top), box (middle) or bars (bottom).

Results

Laboratory Experiments

Visual acuity: This depended on the test used. It was not significantly different between HOTV and Lea Symbols, but it was significantly better [$F(1,2)=1.57$; $p=0.007$] for Kay Pictures (by -0.17 logMAR).

Lateral masking (see Figure 2 right): The effects of flanker separation (SW-EE) on visual acuity were the same for all 3 tests. Lateral masking depended on the surround (optotype, box or bars) [$F(14,28)=9.31$; $p=0.000$] but only in the abutting condition. Optotype surrounds led to greater threshold elevations than did a box ($p=0.015$), or bars ($p=0.025$).

Units of SW-EE revealed lowest variance in threshold elevation (4.75%) across target optotype (picture, symbol, letter) compared to when data were plotted in units of arcmin-EE (21.34%) and OW-EE (32.78%). Critical spacing for all tests (HOTV, Lea Symbols and Kay Pictures) and all surrounds determined statistically (Tukey test) was 3 stroke-widths.

Psychometric function slopes (see Figure 4): Optotype and bar surrounds produced slopes significantly steeper than for a box [$F(2,4)=15.73$; $p=0.013$]. Slopes were steeper for flankers 2-5 SW-EE than for an isolated optotype (slope=4.40±0.42). The steepest slope was for 2 SW-EE (slope=7.93±0.12). Here, a box produced a significantly flatter slope (slope=6.35±0.23) than similar optotypes (slope= 8.46±0.66; $p=0.021$) or bars (slope=8.99±0.10; $p=0.0013$).

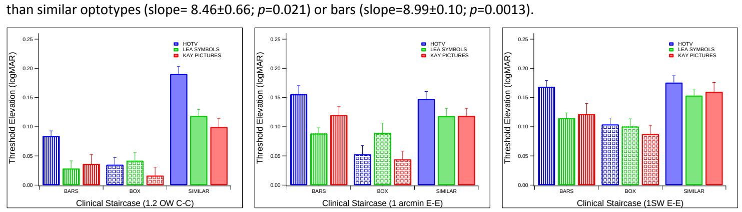

Figure 3: Histograms of visual acuity when surrounds were placed at 3 chosen optimal separations of 1.2 OW-CC, 1 arcmin E-E and 1SW E-E).

Clinical Staircases

Visual acuity: Visual acuity again depended on the test used. It was not significantly different using HOTV and Lea Symbols, but significantly better [$F(1,15)=149.92$; $p=0.000$] with Kay Pictures (by -0.15 logMAR).

Lateral masking: Optotypes surrounding the target resulted in strongest lateral masking (0.17±0.0093 logMAR); then bars (0.13±0.0087 logMAR), then a box (0.10±0.0078 logMAR) (see Figure 4). Threshold elevation depended on separation (see Figure 3) and test used (HOTV, Lea, Kay). One SW-EE resulted in the lowest variance of threshold elevation (12.07%) across target optotype (picture, symbol, letter) compared to 1 arcmin-EE (13.65%) and 1.2 OW-CC (31.29%) (see Table 1). ANOVA found no significant effect of optotype (HOTV, Kay Pictures, Lea Symbols) on visual acuity for flankers placed 1 SW-EE or 1 arcmin-EE. For flankers at1.2 OW-CC, a significant effect of target optotype on acuity [$F(2, 30)=7.17$; $p<0.0056$] was found.

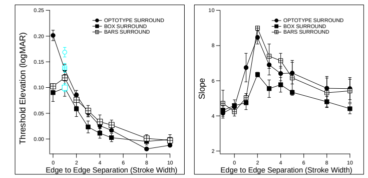

Figure 4 (left): Summary lateral masking functions for different types of surround. Blue points are from 1 SW E-E staircase results. Figure 4 (right): Summary psychometric function slopes for different types of surround.

Assessing the Metrics

	Laboratory MCS		Clinical Staircases		
Unit of Separation	Test (HOTV, Kay, Lea)	Surround (Box, Bars, Similar)	Test (HOTV, Kay, Lea)	Surround (Box, Bars, Similar)	Average
1 SW E-E	4.75%	16.22%	12.07%	25.44%	14.62 ± 0.04%
1 arcmin E-E	21.34%	33.00%	13.65%	36.10%	26.02 ± 0.05%
1.2 OW C-C	32.78%	100.37%	31.29%	74.54%	59.75 ± 0.17%

Table 1:Summary of variances of threshold elevation values taken across test and across surround using different units of separation.

Conclusions

Answers

1. Pictures and symbols produce similar lateral masking effects as letters and can be equally effective clinical tools.
2. The strongest lateral masking is produced by surrounding optotypes, then bars, then a box, especially for naïve observers, e.g., patients (see Figure 4a).
3. Across optotypes, the most conserved separation metric of lateral masking is Stroke-Width Edge-to-Edge.

Clinical Recommendations

1. A single optotype surrounded by other optotypes works well for letters, pictures and symbols in providing consistent lateral masking and would be effective to use in children. Failing this, bars, or then a box placed around a single optotype would both be preferred over using isolated optotypes.
2. Size:stroke ratios in optotype design would ideally be kept constant, however lateral masking effects are approximately constant if separation is kept constant in units of SW-EE.
3. Steeper psychometric slopes indicate greater sensitivity to change. Surrounds of similar optotypes and bars are more effective than a box at providing steeper slopes (see Figure 4b).
4. Visual acuity charts should separate optotypes using units of SW-EE, not OW-EE (as is done currently in commercial charts) in order to more accurately assess real change in visual acuity and lateral masking across age, in disease, or with treatment.

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