Cross-phenotype metrics for foveal lateral masking

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Introduction
Climically, 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 optotypes.

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., 2016); 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 (S-1), Kay Pictures, UK 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 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 separation metrics compare across a box, bars or a box-

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, and 10 OW-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 Hamilson-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 4-down, 1-up staircase combined with a 4AFC response paradigm. Staircases for flanked type (Box, bars, optotype) and separation condition (isolated target and 1-arcmin EE, 1-2 OW-EE separations) were randomized. Staircases were repeated on a separate occasion and results averaged.

Results


Figure 2: Lateral masking functions. Visual acuity (logMAR) for optotype surrounded by symbols at different edge-to-edge separations is subtracted from visual acuity (logMAR) for optotype surrounded by symbols at different edge-to-edge separations (see Table 1). ANOVA found no significant effect of optotype (HOTV, Kay Pictures, Lea Symbols) on visual acuity for flanked 1-EE 2 EE or 1 arcmin EE. For flanked at 2.5 CC, a significant effect of target optotype on acuity (F2.30=7.17; p=0.0056) was found.

Figure 3: Integrates of visual acuity when surrounds were placed at 1 (circles), optimal separations of 1.2 (OW-CC, 1 arcmin-EE and OW-EE).

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 (F2.15=4.69 0000) with Kay Pictures (by 0.15 logMAR). Lateral masking: Optotypes surrounding the target resulted in strongest lateral masking (0.17±0.00 93 logMAR), then bars (0.11±0.01 logMAR), then a box (0.10±0.01 logMAR). (see Figure 4) Threshold elevation depended on separation (see Figure 3) and test used (HOTV, Lea, Kay). One OW-EE resulted in lowest variance of threshold elevation (13.0%) across target optotype (picture, symbol, letter) compared to 1 arcmin EE (13.65%) and 1.2 OW-EE (11.29%) (see Table 1). ANOVA found no significant effect of optotype (HOTV, Kay Pictures, Lea Symbols) on visual acuity for flanked placed 1 EE EE or 1 arcmin EE. For flanked at 2.5 CC, a significant effect of target optotype on acuity (F2.30=7.17; p=0.0056) was found.

Figure 4: Data for the within-subjects factors of separation and test were analyzed using a mixed-effects model (see Table 3). ANOVA showed no significant effect of separation on visual acuity for isolated optotype (F2.30=1.17; p=0.33).

Assessing the Metrics

<table>
<thead>
<tr>
<th>Test</th>
<th>Box Box Bars Bars</th>
<th>Box Box Bars Bars</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOTV</td>
<td>4.7% 16.2% 12.0% 20.4%</td>
<td>14.4% 4.0% 5.9%</td>
<td></td>
</tr>
<tr>
<td>Lea</td>
<td>21.3% 33.0% 13.6% 36.1%</td>
<td>26.0% 3.0%</td>
<td></td>
</tr>
<tr>
<td>Symbols &amp; Pictures</td>
<td>37.8% 100.37% 81.29%</td>
<td>46.45% 50.79% 1.17%</td>
<td></td>
</tr>
</tbody>
</table>

A summary of variance of the threshold elevation across test and across surround using different units of separation.

Conclusions

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 naive observers, e.g., patients (see Figure 4).
3. An optotype, 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, box, or then a box placed around a single optotype would both be preferred over using isolated optotypes.
2. Stroke-ratio in optotype design would ideally be kept constant, however lateral masking effects are approximately constant if separation is kept constant in units of OW-EE.
3. Deeper psychometric slopes indicate greater sensitivity to change. Surrounds of similar optotypes and bars are more effective than a box at providing deeper 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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References