SLOAN LETTER VISUAL ACUITY CHARTS AND COMPUTER MONITOR PIXILATION

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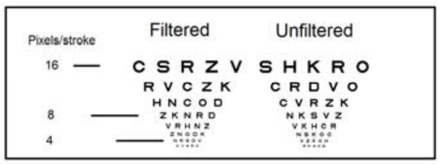
Background

This research investigates how pixilation of computer monitors affects visual acuity measurement. The current ISO Standard 10938:2016 [1] specifies that for presenting acuity charts "Electronic displays shall have pixel size sufficiently small, such that there is no performance difference between the electronically displayed optotype and an optotype that meets the requirements of 4.1.3." Section 4.1.3 specifies luminance and contrast requirements and that "The optotypes shall have sharply defined edges as perceived by an observer with a decimal visual acuity of at least 1,0 at an observation distance of 1/3 the distance at which the optotypes are designed to be used." The ISO standard allows for grey-scaling of letter edges within certain conditions. Beyond that there is little guidance as to what is tolerable pixilation for vision charts. Bailey[2] has suggested that the smallest optotype be rendered such that its critical detail subtends 4 pixels (for a total optotype height of 20 pixels). This research examines the effects of vision chart pixilation on acuity measurements, by rendering the vision charts with different levels of pixilation and examining how this affects visual acuity and test-retest reliability.

Methods



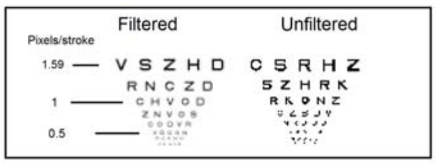


Figure 1. Examples of acuity charts sampled and filtered with different grains

Finely pixelated chart formats used for test distance of 7.41 m, the filtered chart on the left has grey-scaled edges . The unfiltered chart on the right has unsmoothed aliased edges.

Coarsely pixelated chart formats used for test distance of 0.74 m. Filtering and aliasing are more apparent. (Contrast non-linearities may mean grey scales are not printed accurately)

<u>Participants:</u> 10 participants (4F:6M) were aged 19 to 38 years (mean 27.9 ± 7.0) with no history of eye disease and had visual acuity of 20/20 or better. **<u>Stimuli:</u>** An LCD computer monitor (HP ZR2440W) with a pixel size of 0.27 mm/ pixel was used to display stimuli. Background luminance was 289 Cd m-2 and minimum optotype luminance was 2.6 cd m-2, (99.1% Weber Contrast). Sloan letteroptotypes were presented as 8 rows of 5 optotypes in standard logarithmic progression format as described by Bailey and Lovie,3 randomly presented so that a given Sloan letter could appear only once on a row. For each test distance trialled the stimuli were scaled so that the smallest line was -0.40 logMAR (20/8) and the largest 0.30 logMAR. The optotypes were pixilated in two ways. 1) Unfiltered pixilation: if the center of a pixel fell within the bounds of an optotype it was rendered as black. This can lead to aliasing of the pixel edges, which is much more obvious for coarsely sampled optotypes. 2) Filtered pixilation: in which the amount of black and white was integrated across the pixel and rendered as a grey scale. This acts a partial anti-aliasing filter, smoothing the edges of optotypes by grey-scaling. Participants were tested at the following distances 0.47m, 0.74m, 1.17m, 1.86m, 2.85m, 4.67m, 7.41m which gave pixel sizes of 1.97, 1.25, 0.79, 0.500, 0.315, 0.200, 0.125 min of arc/pixel. **<u>Measurement:</u>** The participants' task was to read down a chart until 5 mistakes or more were made on a row. Each subject provided 2 acuity measurements at each test distance for filtered and unfiltered stimuli. logMAR acuities were calculated using letter-by-letter scoring and a termination rule of 3 mistakes on a row.

Results

The relationship between pixel size (min of arc) and acuity threshold is shown, for individual participants, in Figure 2. For each individual data set, a broken line was fitted. Below a certain critical pixel size (P_{crit}), acuity thresholds were independent of pixel size and equal to asymptotic visual acuity (VA_{as}). Above P_{crit} , visual acuity was linearly related to pixel size. Average VA_{as} i.e. acuity for well-sampled stimuli was -0.209 logMAR (SD 0.06) for the filtered letters, just slightly but significantly better than for the unfiltered letters (mean -0.184 logMAR (SD 0.06)) (t_9 = 2.26, p = 0.050). However, average P_{crit} was significantly and substantially (t_9=13.07 $p < 0.001$) larger for filtered stimuli (at 0.0445 log minutes of arc (SD 0.044)or 1.1') than for unfiltered stimuli (at -0.1628 log minutes of arc (SD 0.064) or 0.69'). The relationship between P_{crit} and VA_{as} is shown on log/log axes in Figure 3. The fitted lines show the ratio of P_{crit} (min) to VA_{as}(min) of 1.79 for filtered letters and 1.05 for unfiltered letters. Figure 4 shows Bland-Altman repeatability graphs for logMAR acuity with different levels of pixilation and filtering.

References

1. ISO 10938:2016 Ophthalmic optics -- Chart displays for visual acuity measurement -- Printed, projected and electronic
2. Bailey IL. Visual Acuity. In *Borish's Clinical Refraction 2nd edition* Butterworth Heinemann Elsevier, St Louis. Benjamin WJ Ed ; 2006: 217-246.
3. Bailey IL, Lovie JE. New design principles for visual acuity letter charts. *Am J Optom Physiol Opt.* 1976, 53:740-745.
4. Akutsu H, Bedell HE, Patel SS. Recognition thresholds for letters with simulated dioptric blur. *Optom Vis Sci.* 2000, 77:524-30.

Results (continued)

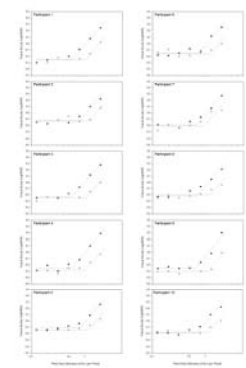


Figure 2. Relationship between visual acuity and pixel size.

Open symbols : filtered optotypes. Closed symbols: unfiltered optotypes.

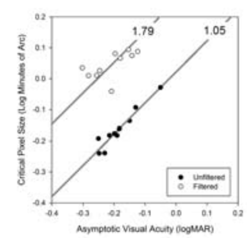


Figure 3. Relationship between VA_{as} and P_{crit}

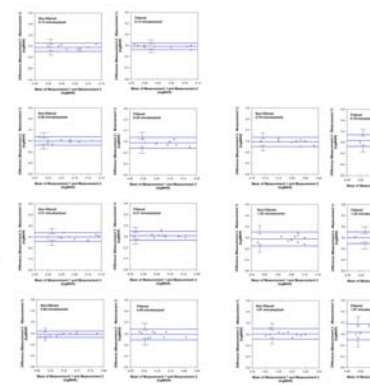


Figure 4. Bland-Altman plots for acuity repeatability

Discussion

1. For practical purposes, threshold letters on acuity charts can be rendered quite coarsely. By convention, the critical detail on Sloan letters is defi arbitrarily as a stroke width of 1/5 of the height of a letter (2.5 cycles/letter), so the ability to discriminate letters that are sampled more coarsely t this appears, superficially, to be supra-Nyquist resolution. However, there is good evidence that the critical spatial frequency for letter identificatio 1.5 cycles/letter,[4] for which the Nyquist frequency would correspond to sampling spacing of 1.67 strokes/pixel, close to the threshold sampling fo here of 1.79 strokes/pixel for filtered letters.

2. Filtering acts to attenuate supra-Nyquist frequencies in an optotype prior to sampling. This reduces aliasing in the sampled image. contradistinction, when unfiltered letters are undersampled, aliased frequencies in the sampled image will affect its legibility. The filter in this stu averaging over the aperture of a pixel, is simple but may not be the optimum filtering profile. It does have relatively good supra-Nyquist freque attenuation for oblique meridians.

3. There are practical implications of these findings. Coarser minimum sampling of a vision chart means that more rows can be fitted on a compu monitor. An example of this is shown below, in which the smallest row (20/10) is rendered with filtering and a sampling rate of 1 pixel per str (approximately 0.25 log units finer than the limits suggested by our study). With such sampling all 14 lines of a standard logMAR chart would fit o standard HD monitor 1920x1080 pixels. At a test distance of 3m (10 feet) this could be produced on a 38" monitor.

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Figure 5. 14 line acuity chart rendered on 1920 x 1080 pixels.

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