Validation of a Visual Impairment Simulator, SightSim™

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1. Background

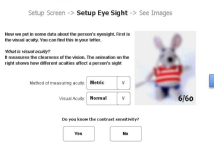
SightSim™ is a software-based visual impairment simulator aimed at the parents and carers of visually impaired children. It can be used in home or school environments to illustrate how the world appears to their child. Images are degraded according to measurements of the child's visual functions, visual acuity and contrast sensitivity.

Visual Acuity (VA): a measure of the visual system's ability to detect and resolve spatially separate objects. Commonly measured in opticians , it is reduced by refractive errors in those without impairments.

Contrast Sensitivity (CS): the ability to detect small changes in luminance when regions are not separated by distinct borders. Reduction can be more distressing for patients than loss of visual acuity.

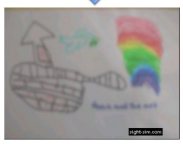
How SightSim™ Works

1. Calibrate screen for pixel density using standard sized card.



2. Input personalised visual acuity and contrast sensitivity measurements.

3. Choose stock image or upload own to degrade.



4. SightSim™ creates simulation of child's sight.

Image Processing Mechanisms

Gaussian Blur (GB): simulates lowered VA by reducing the level of detail in an image, whilst retaining enough information to understand the image subject. Applied in either the time or frequency domain. Magnitude of blur controlled by standard deviation, σ, of Gaussian function.

$$g(x,y,\sigma) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}} \quad [1]$$

Alpha Blending (AB): simulates lowered CS by reducing the number of colours shown in the image around a central point. It adds a foreground colour to a background colour to create a new blending colour.

Healthcare Science

2. Motivation and Aims

Visual impairment in children can be caused by damage to the eyes or brain. It impedes children's ability to learn and carry out everyday tasks [2]. When children are diagnosed, their parents are given a numerical explanation of their child's sight using visual acuity and contrast sensitivity measurements. This can leave parents confused about what they can do to practically help their child.

Objectives: To verify the SightSim™ software, identifying errors within the code that may have caused the off-set (error) between the measured and simulated acuity identified in a preliminary validation. To design and carry out further validation experiments to assess the accuracy of the visual acuity and contrast sensitivity simulations.

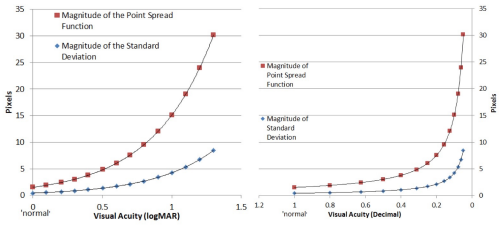
Image credit: www.sight-sim.co.uk

3. Verification and Preliminary Validation

Verification Gold Standard:

- Gold standard for SightSim™ Java visual acuity image processing algorithm created in Matlab (MathWorks, UK).
- Testing with single pixel element images identified four errors;
- (**A**) resizing algorithm, (**B**) relationship between VA and standard deviation of Gaussian, (**C**) pixel scaling and (**D**) viewing distance.
- Errors removed by; (**A**) limiting size of test charts, (**B, C**) altering equations implemented in Gaussian blur algorithm and (**D**) correcting erroneous viewing distance value to 60 cm.
- Version of software prepared for validation.

(A) Single pixel element test images (vertical, horizontal)



*Standard deviation of Gaussian (pixels) against acuity (logMAR – exponential relationship, decimal – power relationship) (**B**)*

Preliminary Validation:

- Carried out in 2012.
- 13 subjects tested using one visual acuity test (ETDRS).
- Two test platforms used (MacBook and ASUS) at a testing distance of 45 cm.
- Results showed measured acuity was better than simulated acuity by approximately 0.2 logMAR for acuities poorer than 0.3 logMAR.

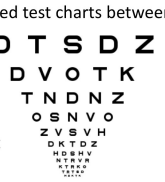
4. Current Validation

Protocol:

- 28 ophthalmologically and neurologically normal subjects were tested using the two VA and one CS test (mean age = 39, range = (19 – 62) years).
- ETDRS chart and Landolt C's were degraded for a range of simulated acuity levels. Subjects' acuity measured using degraded test charts between 1.3 and 0.0 logMAR.
- The Pelli-Robson chart was degraded for range of simulated contrast levels. Subjects contrast threshold measured using degraded test charts between 0.5 and 100% contrast.
- Forced choice methodology adopted.

Test Charts:

- Two visual acuity and one contrast sensitivity charts prepared; ETDRS, Landolt C and Pelli-Robson.
- Tests prepared for two screens (HP and Acer) and two testing distances (60 cm and 120 cm)



ETDRS V.2 for HP screen

Pelli-Robson for Acer screen

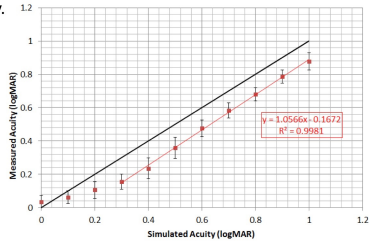
Landolt C's for HP screen

5. Key Results

Visual Acuity Simulation:

- Analysed using data from ETDRS and Landolt C tests.
- ETDRS data showed that, on average, measured acuity 0.1 logMAR better than simulated acuity for acuities 0.3 logMAR and poorer.
- Regression line fitted to linear portion of data had equation $y = 1.06x - 0.17$ *Equation 1*
  y = measured acuity, x = simulated acuity.

95% CI revealed mean measured acuity between **0.13 - 0.2** logMAR better than simulated acuity for acuities 0.2 logMAR and poorer.

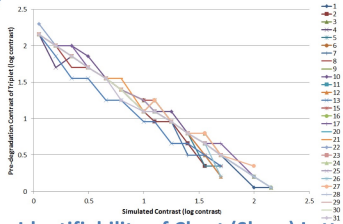


Testing Distance:

- Landolt C data showed Gaussian blur applied by SightSim™ is more accurate at a viewing distance of 60 cm than 120 cm.
- Viewing distance defined as 60 cm within SightSim™ code.

Comparison with **Preliminary** ETDRS data showed that changes to the software and validation protocol had increased the accuracy of visual acuity simulation.

6. Further Results



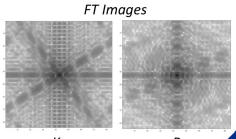
Contrast Sensitivity Simulation:

- Subject were able to read lower contrast triplets as simulated contrast threshold increased.
- 16 threshold estimates for each subject approximately equal.
- Response was found to be age dependent; younger participants had a lower contrast threshold.

Identifiability of Chart (Sloan) Letters:

- Based on alternative (incorrect) answers given by subjects during ETDRS test, letters were ranked by difficulty.
- Using Fourier transforms, images and histograms of letters' spatial frequency content were produced.

FT Images



K *R*

7. Discussion and Conclusions

Limitations: At small viewing distances (e.g 60 cm) there is an accuracy limit to the display of the smallest chart letters due to the pixel density of screen and the intrinsic blur of the visual system. This accounts for measured acuity exceeding simulated acuity at the best acuities (0.3-0.0 logMAR). Subject's improved performance in the Landolt C test compared to the ETDRS test highlighted this is not a suitable validation test for SightSim™. The luminance qualities of the test screen may affect the accuracy of the contrast sensitivity simulation. The subject cohort was too small to accurately rank chart (Sloan) letters by identifiability.

Conclusion: The first stage of the project involved identifying sources of error within the SightSim™ code whose existence had been highlighted by the results of the preliminary validation. Reviewing the preliminary protocol and results informed the design of further validation experiments. The results of the current validation show an off-set (error) is still present in the visual acuity simulation and quantified the contrast sensitivity simulation for the first time.

As a result of this work the SightSim™ project is likely to redeveloped as an Android mobile application. Understanding of the image filtering methods has increased and quantifying the accuracy of the simulations presents an opportunity to further improve their performance in future.

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VIA VERITAS VITA

References

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2. Lueck A, G Dutton. *Vision and the Brain.* AFB Press, 1st edition, 2015.