The Contrast Sensitivity Function in children: Bayesian adaptive estimation using QUEST+

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Background

- Compared to visual acuity alone, the full Contrast Sensitivity Function (CSF) provides important clinical information that can be used for diagnosis and monitoring [1].
- However, in clinical vision-science, we currently lack a robust, child-friendly measure of the CSF: current measures of CSF are too slow.
- Bayesian adaptive estimation (e.g., the "qCSF[2]") provides faster and more robust measures than traditional psychophysical techniques.

Aims

- Evaluation of a novel implementation of Bayesian adaptive CSF estimation, using QUEST+, in children aged 4 -14 years.
- Specifically: assessment of the accuracy, speed, and test-retest reliability of this novel method.

Methods

Participants: 59 children aged 4-14 years and 28 adults (see Fig 5B for age distribution). All participants reported normal vision.

Stimuli: Horizontal Gabor patches: ranging from 2 to 30 cycles per degree (cpd) in Spatial Frequency, and from 0.0001 to 1 in Michelson Contrast.

Procedure: Four alternative forced choice (4AFC) Gabor detection. The total number of trials was determined by the adaptive algorithms. Participants completed the same test using two different algorithms (QUEST+ vs Staircase), and/or completed the same algorithm twice so that we could assess test-retest reliability.

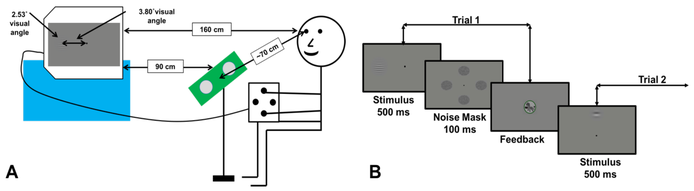


Fig 1. Experiment set-up. **A)** An eye-tracker was used to record the participant's gaze location. **B)** Each trial started with a fixation point and continued by presentation of the stimuli and presentation of feedback (i.e., happy zebra (hit) or sad face (miss)).

Reference Algorithm: 8 weighted "down-2 up-1" staircases performed independently at 8 spatial frequencies (CSF fitted post-hoc).

Test Algorithm: Fitting a 3-parameter CSF model in a 2D parameter space using QUEST+[3] (see Fig 2 for details). The key advantages of the QUEST+ algorithm are that it:
1. provides rapid and flexible estimation of the parameters of a psychophysical model, 2. advises the user on the most appropriate stimuli to present, and testing termination time, 3. uses prior information, 4. determines the maximally informative stimulus on each trial, 5. fits arbitrarily complex models, 6. allows to vary multiple stimulus properties simultaneously.
The code used to implement QUEST+ is freely available at: https://github.com/petejonze/QuestPlus.

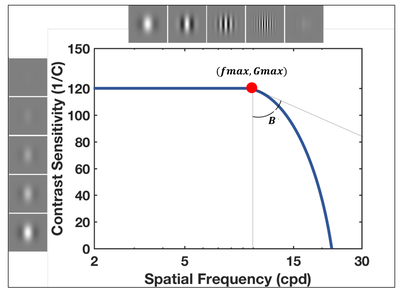


Fig 2. Our novel QUEST+ CSF estimation model (similar to the qCSF[2]). The model has 3 free parameters: (1) peak contrast sensitivity, G_{max}; (2) peak frequency, F_{max}; (3) rate of fall-off, B. The model also contained 3 fixed parameters: lapse rate (0.1), psychometric slope (3), and guess rate (0.25). The stimulus (i.e., Gabor patch) has two parameters: frequency and contrast.

Results

Agreement of test duration and accuracy

CSFs acquired using QUEST+ stabilized after 50 trials (~2 minutes), providing substantive speed benefits in comparison to the traditional staircase method.

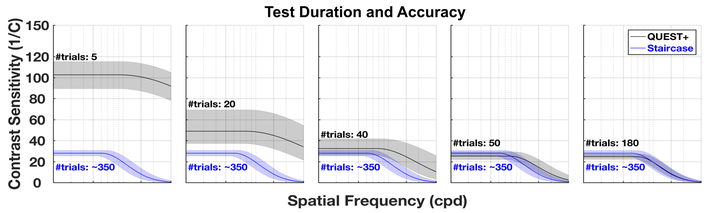


Fig 3. Mean ± 95%CI CSFs: the QUEST+ CSF (black) and the adaptive staircase method (blue). Each panel shows the average QUEST+ CSF estimate for all the participants obtained with different number of trials (adaptive staircase CSF estimate using all ~350 trials is shown in every panel, for reference). Shaded region: bootstrapped $CI_{95\%}$.

Test Reliability

Estimates were more reliable with the QUEST+ than with the traditional staircase method. This was true for all 3 parameters and both age groups, although children's measures were consistently less reliable than adults.

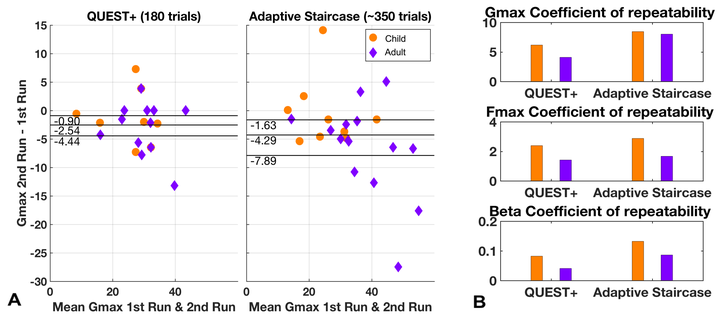


Fig 4. A) Bland-Altman plot showing the test-retest repeatability of parameter G_{max} (see Fig 2). Data points represent individual children (red circles) and adults (blue diamonds), **B)** Coefficient of repeatability for each of the three CSF estimation parameters, broken down by method and age-group. Larger values = less reliable.

Development of contrast sensitivity

Parameters f_{max} and *Beta* were not observed to change with age. However, G_{max} (peak contrast sensitivity) did exhibit a significant developmental effect (F_{112} = *23.2*, p < .001, r^2 = 0.17). This developmental effect (7.44; mean difference between young children and adults) was larger than, but similar in magnitude to the individual variability between observers (4.60; median absolute deviation from the regression line shown in Fig 5B).

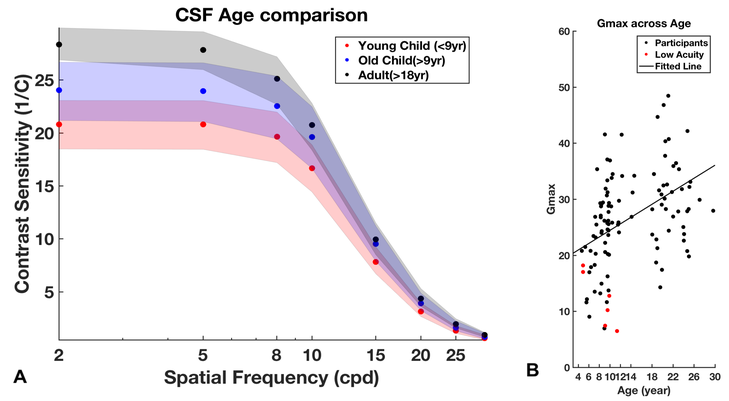


Fig 5. Development of contrast sensitivity with age **A)** mean CSF grouped by age for young children (<9yr; red), old children (>=9yr; blue), and adults (>=18yr; black). Each marker represents mean contrast sensitivity as a function of spatial frequency: derived using the combined data from both adaptive methods (QUEST+ and Staircase). The shaded region is the bootstrapped $CI_{95\%}$. **B)** Development of parameter G_{max} across age. Each data point represents one participant. The black line is the least mean squared regression slope. Participants with low acuity are shown in red, and were excluded from all analyses.

Discussion

Bayesian adaptive methods allow CSF estimates to be made in children. Specifically:

- CSF estimates were more reliable than traditional psychophysical methods.
- Robust estimates could be made in children aged 4 to 14 in only 50 trials (~2 mins).

A developmental effect was observed at low frequencies (i.e., G_{max}). While this effect was larger than the amount of individual variability within age groups, they were of similar magnitude.

Future Work

We are currently evaluating the feasibility of making CSF estimates in children with inherited retinal dystrophies (achromatopsia).

If you are interested in using this test for your own projects then please get in touch (m.farahbakhsh.16@ucl.ac.uk), or download the code for free online (see Methods).

References

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