Computing Ishihara-Style Stimuli From Spectra: Inverse Design of Reflectance Pairs With Prescribed Observer-Dependent Confusability

Satyajeeth Suresh Kannan
Innovation Academy · Mary's Lab
github.com/JeetuSK0808/maryslab

Preprint · August 2026 · Mary's Lab technical report TR-14

ABSTRACT

Clinical colour vision tests use plates whose figure and ground separate for a normal trichromat and converge for a dichromat. The classical plates were developed empirically with pigments available a century ago, and their construction is not parameterisable: a practitioner cannot request a plate targeting a specific deficiency type and severity. We compute such stimuli directly. Given a target observer model, we search reflectance space for a pair maximising separation for normal vision subject to a confusion ceiling under the target, using the same evolution strategy employed elsewhere in this series. For full deuteranopia we obtain a pair separated by 0.6273 ΔE_{OK} for a normal trichromat and 0.01996 for the target observer, a ratio of 31.4. We state plainly that this is stimulus *design*, not a validated diagnostic, and that clinical use would require psychophysical validation this work does not attempt.

Keywords: color vision testing; inverse design; Ishihara; dichromacy; stimulus design

1. Introduction

Pseudoisochromatic plates exploit a structural fact: dichromacy is a dimensional reduction, so pairs of colors that are distinct in three dimensions can be identical in two. A plate whose figure and ground form such a pair is visible to one observer and not another.

The classical plates are fixed artifacts. They were designed empirically, with the pigments and printing of their era, and they target the deficiencies their designers had in mind. A researcher who wants a stimulus tuned to a particular type and severity — or one built from reflectances that a specific printing process can achieve — has no principled route to it.

Because the underlying relationship is colorimetric, the stimulus is computable.

2. Method

Let `D` be the target observer model — a Machado matrix at a given type and severity. We search for a pair of reflectances (r_1, r_2) maximising ΔE_{OK} under normal vision subject to ΔE_{OK} under `D` remaining below a confusion ceiling.

The search runs over the same low-order polynomial basis used in TR-10, keeping solutions smooth and physically plausible, and uses the same (1+1) evolution strategy: the objective is again a constrained extremum whose active constraint changes during the search.

Searching reflectance space rather than colour space matters here for a specific reason. A pair specified as colors is only confusable under the illuminant assumed when the colors were chosen; a pair specified as reflectances can be evaluated, and constrained, under whatever illuminant the test will actually be viewed in.

3. Evaluation

Inputs are synthetic and no human subjects were involved. The evaluation measures the designed stimulus against the observer model used to design it, which establishes that the optimisation achieved its objective — not that the stimulus functions as a test for real observers.

Table 1. Designed reflectance pair targeting full deuteranopia. Separation is ΔE_OK under each observer model; the ratio is the design objective.

quantity	value
separation, normal trichromat	0.6273
separation, deutan (severity 1.0)	0.01996
separation ratio	31.4

The designed pair is well separated for a normal trichromat and close to confusable under the target model, with a ratio of 31.4. As an optimisation result this is unambiguous: the search found reflectances with the requested observer-dependent behaviour.

The gap between that statement and a clinical claim is wide, and we want it visible rather than implied. A stimulus that separates under a model separates under a model. Whether a person with deuteranomaly cannot resolve this pair on a printed card under clinic lighting is a psychophysical question, and answering it requires subjects, a protocol, and ethical review. The instrument produces candidate stimuli for such a study; it does not substitute for one.

Reproducing these numbers

Clone `github.com/JeetuSK0808/maryslab` and run `node papers/build/experiments.mjs`. Every figure in this report is written by that script into `papers/build/results.json`; the instrument itself is exercised by `design_discrimination_test`. The engines carry a 401-vector conformance suite shared by a TypeScript reference implementation, a C++20 core, and a WebAssembly build, so a reported number is a property of the specification rather than of one implementation.

4. Limitations

This section states what the result does not establish. It is written to be read before the abstract is quoted.

- **There is no measured-data section in this report, and no dataset would supply one.** Other reports in this series were re-run against snapshot `usgs-splib07a-1`, which closed the gap between a synthetic demonstration and a measured result. That move is unavailable here: the quantity this instrument asserts is what a *person* can distinguish, and no library of reflectance measurements — however large or however real — contains a human judgement. The gap in this report is closed by a psychophysical study with consenting participants, or it is not closed. It remains open.
- **This is not a diagnostic and must not be used as one.** No psychophysical validation has been performed. Clinical colour vision assessment requires validated instruments and qualified administration.
- **Confusability is asserted under a model.** The Machado model parameterises dichromacy; real colour vision deficiency varies between individuals, and anomalous trichromacy in particular is a spectrum that a single severity parameter represents only coarsely.
- **Designed reflectances are targets.** Whether a printing process can achieve the designed curves, under the paper and inks used, is a separate question. A plate printed with pigments that approximate the design only loosely may not preserve the property.
- **Viewing conditions are part of the stimulus.** The pair is designed under a declared illuminant; viewing it under another changes both separations.
- **A seeded result is not an optimum.** The reported pair is the best found within the search budget.
- **Prior art was surveyed informally.** Pseudoisochromatic plate design and CVD simulation are both established; a search found no tool computing stimulus pairs in reflectance space against a parameterised observer model.

5. Acknowledgements and disclosure

The instruments described here were implemented in Mary's Lab, an open-source computational color science project. Software design, implementation, and the preparation of this report were carried out with substantial assistance from a large language model (Anthropic Claude), under the author's direction and review. All numerical results were produced by executing the released code; none were generated by a language model. The author is responsible for the claims made here.

References

1. Ishihara, S. (1917). *Tests for Colour-Blindness*. Handaya, Tokyo.
2. Farnsworth, D. (1943). The Farnsworth–Munsell 100-hue and dichotomous test for color vision. *Journal of the Optical Society of America*, 33(10), 568–578.
3. Machado, G. M., Oliveira, M. M., and Fernandes, L. A. F. (2009). A physiologically-based model for simulation of color vision deficiency. *IEEE Transactions on Visualization and Computer Graphics*, 15(6), 1291–1298.
4. Ottosson, B. (2020). *A perceptual color space for image processing (Oklab)*. bottosson.github.io.
5. CIE (2004). *Colorimetry, 3rd edition*. CIE 15:2004. Commission Internationale de l'Éclairage, Vienna.
6. Rechenberg, I. (1973). *Evolutionsstrategie: Optimierung technischer Systeme nach Prinzipien der biologischen Evolution*. Frommann-Holzboog.
7. Wyszecki, G. and Stiles, W. S. (1982). *Color Science: Concepts and Methods, Quantitative Data and Formulae*, 2nd edition. Wiley.
8. Brettel, H., Viénot, F., and Mollon, J. D. (1997). Computerized simulation of color appearance for dichromats. *Journal of the Optical Society of America A*, 14(10), 2647–2655.

Source, engines, and the script that produced every number in this report: `github.com/JeetuSK0808/maryslab`. Results regenerate with `node papers/build/experiments.mjs`. All inputs are synthetic; see §Limitations. Prepared with AI assistance (see Acknowledgements).