FN-Wahrnehmung-Gegenfarben-EN-v0.1-2026-05-17

Research Note — Afterimages and Opponent Colours

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1. Thesis

Module 09 established trichromacy: three cone types produce colour perception (Young-Helmholtz). L2 showed lateral inhibition for brightness. L3 connects both and shows that trichromacy alone *does not suffice*: colour processing is **two-stage**. On the first stage are three cones (LMS), on the second three **opponent channels** — red-green, blue-yellow, light-dark (Hering). Three phenomena refute the assumption that colour is stimulus-fixed and purely trichromatically encoded: **negative afterimages** (colour arises without a coloured stimulus), **simultaneous colour contrast** (colour depends on context — lateral inhibition in colour space) and **impossible colours** (there is no “reddish green” because the opponent axes are bipolar). The module resolves the historical dispute Young-Helmholtz vs. Hering: **both were right, on different levels.** It closes the colour thread Module 09 → L2 → L3.

2. Assumptions

1. The three cone types (L, M, S) have known, overlapping spectral sensitivities. Here roughly approximated as an RGB→LMS matrix.
2. The opponent transformation is linear: achromatic = L+M, red-green = L−M, blue-yellow = S−(L+M)/2.
3. Adaptation reduces the sensitivity of strongly stimulated cones (fatigue/bleaching).
4. Lateral inhibition acts in the opponent channels analogously to L2 (brightness).
5. The bipolarity of the channels is structural: a channel can only signal one pole at a time.

3. Mathematical model

M1 — “trichromacy suffices, colour is stimulus-fixed”: The cone response (L,M,S) determines the colour completely; it depends only on the current stimulus and is not encoded in opponent pairs.

Opponent transformation: $$A = L + M, \qquad RG = L - M, \qquad BY = S - \tfrac{L+M}{2}.$$

M2 — afterimage (adaptation): Cone sensitivity drops proportionally to stimulation, $s_i \to s_i(1 - a\,r_i)$. A neutral test stimulus (white) then produces an unbalanced response → the opponent colour of the adaptation stimulus.

M3 — colour contrast (lateral inhibition): The ground inhibits the opponent channels of the patch: induced $= \text{patch} - k\cdot\text{ground}$ (in opponent coordinates). A grey patch takes on the opponent colour of the ground.

M4 — impossible colours: Since RG and BY are bipolar, no colour can have both $RG>0$ (red) and $RG<0$ (green). “Reddish green” is structurally excluded; “reddish yellow” (orange, different axes) is possible.

Symbol	Meaning	Unit
L,M,S	cone responses	—
A,RG,BY	opponent channels	—
a	adaptation strength	—
k	inhibition weight	—

4. Parameters

Three scenarios:

Scenario	Setup
A afterimage	adaptation to saturated red, test white, $a=0.6$
B colour contrast	grey patch (0.5) on red and green ground, $k=0.5$
C impossible colours	bipolarity of the opponent axes

Tolerance set in advance: $\varepsilon = 5\%$ (opponent response).

5. Prediction

Scenario	Expectation
A	red adaptation → green/cyan afterimage on white
B	grey patch greenish on red, reddish on green
C	reddish green / bluish yellow impossible, orange/turquoise possible

6. Falsification criterion

M1 (“colour is stimulus-fixed and purely trichromatic”) is refuted if colour arises without a coloured stimulus (afterimage), if a neutral patch appears context-dependently coloured (contrast), or if the perceivable/impossible colours follow the opponent structure instead of pure trichromacy.

7. Competing models

- **K1 — pure trichromacy (M1, Young-Helmholtz):** tested

baseline model; explains colour mixing but not afterimages, contrast and impossible colours.
- **K2 — opponent theory (Hering):** three bipolar channels; explains exactly the phenomena K1 does not.
- **K3 — two-stage theory (Hurvich & Jameson):** cones *and* opponents; the modern synthesis resolving the dispute.
- **K4 — lateral inhibition in colour space:** opponent contrast as spatial interaction (connects to L2).
- **K5 — retinal vs. cortical processing:** opponent channels arise already in the retina (ganglion cells), further processed in cortex.
- **K6 — adaptation/von-Kries scaling:** model of cone adaptation for colour constancy and afterimages.

8. Domain of failure

- **Rough RGB→LMS matrix:** a didactic approximation, not the exact CIE transformation; the numbers are qualitative, the direction robust.
- **Linear opponent transformation:** real opponent channels are nonlinear and adaptive; the model is a first approximation.
- **Adaptation simplified:** cone fatigue is modelled as a simple factor, not as time-resolved dynamics (bleaching/regeneration).
- **Individual differences:** colour deficiency (dichromacy, anomalies) changes the cone basis; normal vision assumed here.
- **Impossible colours under special conditions:** with stabilised retinal images, "forbidden" colours can be partly produced in experiments (Crane & Piantanida 1983) — a boundary the simple model does not cover.
- **Higher colour cognition:** colour categories, language and memory additionally affect colour perception; not treated here.

9. Simulation

Numerical evaluation in `gegenfarben_simulation.py`:

1. RGB→LMS cone responses and opponent transformation.
2. Scenario A: adaptation to red, test white; afterimage opponent colour.
3. Scenario B: grey patch on red/green ground; lateral inhibition in the opponent channels.
4. Scenario C: possible vs. impossible colour mixtures from the bipolarity.

Results in `gegenfarben_results.json`. Plot as `gegenfarben_szenen.svg` (four subplots: cone adaptation, colour contrast in opponent space, opponent circle, LMS→opponent).

10. Result

10.1 A negative afterimage

Quantity	Value
adaptation stimulus	saturated red
test stimulus	white
afterimage red-green channel	−0.338
afterimage colour	green-blue (cyan)
Assessment M1	**refuted**

10.2 B simultaneous colour contrast

Quantity	Value
grey patch	neutral (0.5)
on red ground (red-green)	−0.126 → greenish
on green ground (red-green)	+0.105 → reddish
Assessment M1	**refuted**

10.3 C impossible colours

possible (different axes)	impossible (same axis)
orange (red+yellow)	reddish green
turquoise (green+blue)	bluish yellow
magenta (red+blue)	—
Assessment M1	**refuted**

Plot: `gegenfarben_szenen.svg`.

11. Assessment

M1 ("colour is stimulus-fixed and purely trichromatic") is refuted in all three scenarios.

Scenario A (afterimage) is the classical evidence for opponent theory. If one stares long at a red surface and then looks at white, a green-cyan afterimage appears — the opponent colour. The mechanism: the red-sensitive L cones fatigue from the continuous stimulation (their sensitivity drops). Looking afterwards at white, which would stimulate all cones equally, the exhausted L cones respond more weakly than the rested M and S cones. In the red-green opponent channel (RG = L−M) an imbalance towards the green side arises (−0.338). Decisive for refuting M1: **here a colour perception arises without a coloured stimulus** — on the white wall there is physically no green. Pure trichromacy, which couples colour directly to the stimulus, cannot explain this; cone adaptation plus the opponent structure explains it exactly.

Scenario B (colour contrast) is the direct continuation of L2 in colour space. A neutral grey patch appears greenish on red ground (RG −0.126), reddish on green ground (RG +0.105). The mechanism is the same lateral inhibition as in brightness simultaneous contrast (L2), only now in the opponent channels: the red ground excites the red side of the RG channel and inhibits it in the patch, so that the patch appears shifted towards the green side. This is the finest connection between L2 and L3: **one principle (lateral inhibition), two applications (brightness and colour).** Painters have used this for centuries — a grey can be "tinted" by the coloured surround without changing it itself (Chevreul's law of simultaneous contrast, which shaped the Gobelins manufactory and later the Pointillists).

Scenario C (impossible colours) is the strongest and subtlest evidence. We can effortlessly imagine orange (a "reddish yellow") and turquoise (a "greenish blue") — but no "reddish green" and no "bluish yellow". Why? Because red and green are the two poles of the *same* channel (RG), likewise blue and yellow (BY). A channel cannot signal both poles at once — just as a balance cannot swing left and right simultaneously. Colours of *different* axes, by contrast, combine freely (orange = RG+ and BY−, turquoise = RG− and BY+). This is a **prediction that pure trichromacy does not make**: from three independent cones no prohibition of certain colour combinations follows. Only the opponent structure explains why the colour space is “shaped” exactly as we experience it. Notably, under laboratory conditions with stabilised retinal images (Crane & Piantanida 1983), subjects actually reported “forbidden” colours — a fascinating boundary that confirms the rule by showing under which special conditions it breaks.

The central insight — the two-stage theory: Module 09 showed trichromacy (three cones), and it is right — at the receptor level. L3 shows the opponents (three bipolar channels), and they are also right — at the neural processing level. Historically Young-Helmholtz (three colours) and Hering (opponent colours) disputed bitterly; the modern two-stage theory (Hurvich & Jameson 1957) resolved the dispute: the cones encode trichromatically, then the ganglion cells recompute the cone signals into opponent channels. **Both theories describe the same processing at different stations.** This is one of the most elegant resolutions of a scientific dispute — and a model example that seemingly incompatible models can hit different levels of the same system.

Connection to previous modules: - **Module 09 Colour Mixing:** trichromacy as the first stage; L3 adds the second (opponents). Together they form the complete picture of colour perception. - **Module L2 Brightness Contrast:** lateral inhibition, here applied to colour space. Colour contrast is brightness contrast in colour. - **Module 02 Cave Allegory:** afterimages show particularly drastically that perception is not the stimulus — we see green where physically there is only white.

12. Next test

Module L4 Motion Illusions (phi phenomenon, motion aftereffect/waterfall illusion) as the next step — the temporal analogue to the afterimages: after motion adaptation, stillness appears as counter-motion. Or **Module L5 bistable perception** (Necker cube, ambiguous figures).

Possible extension Module L3 v0.2: exact CIE cone sensitivities and opponent transformation; colour deficiency (dichromacy simulation); colour constancy quantitatively (von Kries, Retinex); the stabilised “forbidden” colours; Chevreul’s law and the Pointillists.

Appendix A — Cross-references

- Practice explanation: `PRAXIS-Gegenfarben-EN.md` (follows)
- Companion paper: `BEGLEITPAPIER-Gegenfarben-EN.md` (follows)
- Tool: `OPPONENS.html` (follows) — *Lat. opponens, the opposing one*
- Code: `gegenfarben_simulation.py`
- Plot: `gegenfarben_szenen.svg`
- Result data: `gegenfarben_results.json`
- Predecessor modules: Module 09 Colour Mixing, Module L2 Brightness Contrast, Module 02 Cave Allegory
- Follow-up modules (planned): L4 Motion, L5 Bistability, L6 Gestalt

Appendix B — External stocktaking

- **Hering (1878)** *Zur Lehre vom Lichtsinne* — opponent theory.
- **Hurvich & Jameson (1957)** — quantitative opponent theory, two-stage model.
- **De Valois et al. (1966)** — opponent cells in the lateral geniculate nucleus.

- **Chevreul (1839)** — law of simultaneous colour contrast.
- **Crane & Piantanida (1983)** — “forbidden” colours with stabilised images.

What the workshop note adds: three opponent-colour phenomena in a unified falsification format; the explicit LMS→opponent transformation; the connection of L2 (lateral inhibition) and Module 09 (trichromacy) into the two-stage theory; the bridges to modules 09, L2, 02.

Appendix C — Sources

- Hering, E. (1878). *Zur Lehre vom Lichtsinne*. Carl Gerold’s Sohn, Vienna.
- Hurvich, L. M.; Jameson, D. (1957). An opponent-process theory of color vision. *Psychological Review* 64:384–404.
- De Valois, R. L.; Abramov, I.; Jacobs, G. H. (1966). Analysis of response patterns of LGN cells. *J. Opt. Soc. Am.* 56:966–977.
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- Crane, H. D.; Piantanida, T. P. (1983). On seeing reddish green and yellowish blue. *Science* 221:1078–1080.

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