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Optimal Transport of Hallucinatory Colors

Lemona Xinxuan Zhang, Tonglin Yan, Ken Takeda, Matteo Paganin

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1. Introduction

Background

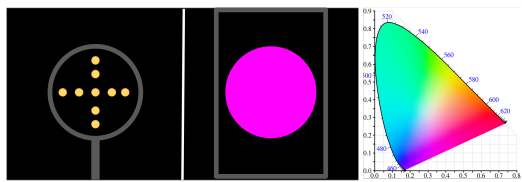
When stimulated with intense flickering white light under a Ganzfeld setting, people often report seeing hallucinatory colors, geometric forms and patterns. Previous studies have characterized common form hallucinations, including ones consistent with the psychedelic-induced Klvier form constants¹, and proposed models for their occurrence^{2,3,4,5}. However, there has been no recent systematic and detailed investigation of the mechanism or phenomenology of the colors perceived during flicker light stimulation. This project is based on a behavioral study which looked at the colors people saw when viewing an intense flicker at different frequencies, across two sessions. Given previous evidence for the role of frequency information in the perception of subjective colours^{6,7,8}, we aim to better characterise the relationship between flicker frequency and flicker-induced colours and to establish a proof of concept for future studies on the spectral code of subjective colors.

Research questions

- What is the relationship between frequency and colors? Is there any frequency-color correspondence?
- If there is a correspondence, is it consistent within the same individual?
- Is it consistent across individuals?

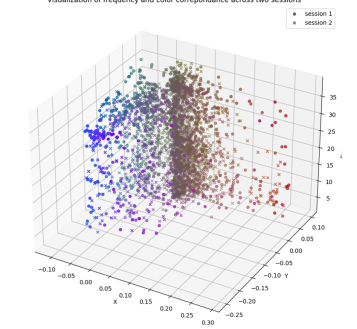
Experimental paradigm

- Session 1: explore frequencies, match colors
- Session 2: fixed frequencies from session 1, forced color matches



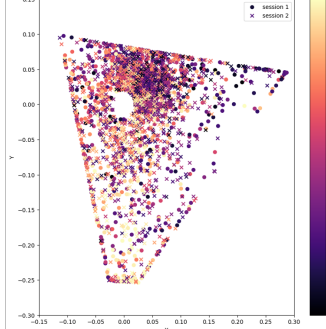
2. Raw dataset visualization

Visualization of frequency and color correspondence across two sessions



3D visualization, where z-axis represents frequency

2D Visualization of dataset



2D visualization, where the color of points corresponds to the frequency scale bar on the right side

4. Conclusion

- The correspondence between flicker frequency and hallucinatory colors is a many-to-many mapping
- Specific flicker frequencies elicited consistent colors within some individuals, confirmed by optimal transport results.
- There seems to be no consistent frequency-color correspondence across individuals, as shown by the GWOT results.

Acknowledgements

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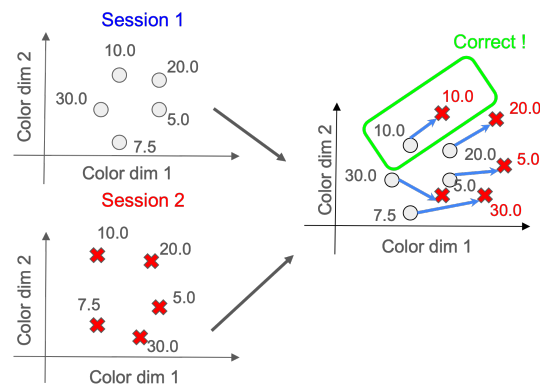
References

1. Alford, C., Pitt, P., Keenan, S., Williams, J. (2011). Flicker-light induced visual phenomena: Frequency dependence and specificity of whole percept and percept features. *Consciousness and Cognition*, 20(4), 1344-1362.
2. Ermentrout, G. B., Cross, J. D. (1979). A mathematical theory of visual hallucination patterns. *Biological Cybernetics*, 3(3), 187-190.
3. Chaitin, G. J., Sussner, R. M. E., Jermolovs, E. J., Cohen, S. K., Blanton, J. A., Indurkha, M. H. (2022). Spectral-temporal resonance in mouse primary visual cortex. *PLoS Computational Biology*, 18(7), e1009216.
4. Rudi, M., Sussner, M., Ermentrout, G. (2011). A Model for the Origin and Properties of Flicker-Induced Geometric Phantasms. *PLoS Computational Biology*, 7(9), e1002158.
5. Jiang, J. X., Schmidt, M. E., Barlow, M. T., Bornemann, J., Kalloni, E., Sponholz, T., Schmidt, T. T. (2023). Flicker light stimulation induces thalamocortical hyperexcitability with LGN and higher-order thalamic nuclei. *Insight Neurosciences*.
6. Berler, C., Elliott, M. A. (2006). Flicker-induced color and form: Interdependencies and relation to stimulation frequency and phase. *Consciousness and Cognition*, 15(1), 175-196.
7. Bertram, C., Elliott, M. (2001). Flicker's Colors Are Induced By Flickering Monochromatic Light.
8. Scheidt, R., Vaeland, R. (2013). The Flickering Wheel Illusion: When 'Flashing' Makes a Sense: Wheel Flicker. *Journal of Neuroscience*, 33(31), 13426-13504.
9. Guoj, K., Anil, Z. J., Kim T., Natsugai, T. and Masufusa O. (2024). Is any "red" your "red"? Unsupervised alignment of qualia structures via optimal transport.

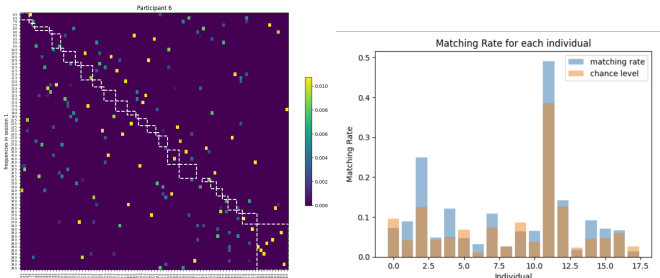
3. Methodology and results

I. Optimal transport

Most efficient way of mass transport between two sets of data points within the same space (color matches of two sessions for the same participant)



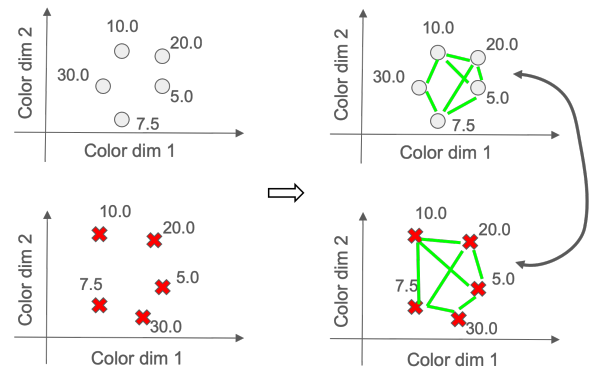
Results



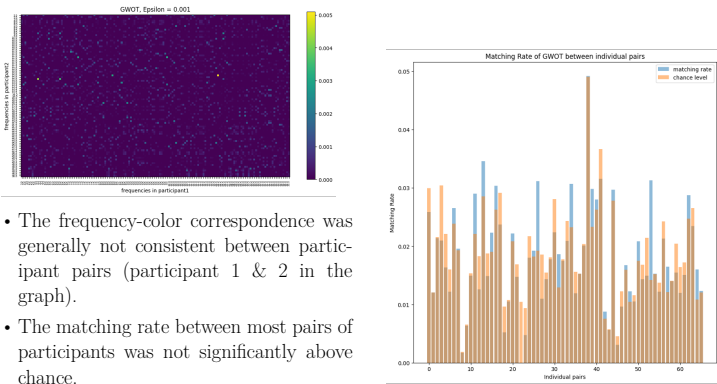
- If the matches across two sessions are consistent, colored points should fall into the white rectangles, and matching rates between session 1 and session 2 frequency labels should be higher than chance level.
- For most participants, the matching rate is higher than chance level.

II. Gromov-Wasserstein optimal transport⁹ (GWOT)

Most efficient way of mass transport between two sets of data points in different spaces (color matches within the same session between different participants)



Results



- The frequency-color correspondence was generally not consistent between participant pairs (participant 1 & 2 in the graph).
- The matching rate between most pairs of participants was not significantly above chance.