Microfluctuations in Ocular Accommodation Across Target Distance and Light Spectrum

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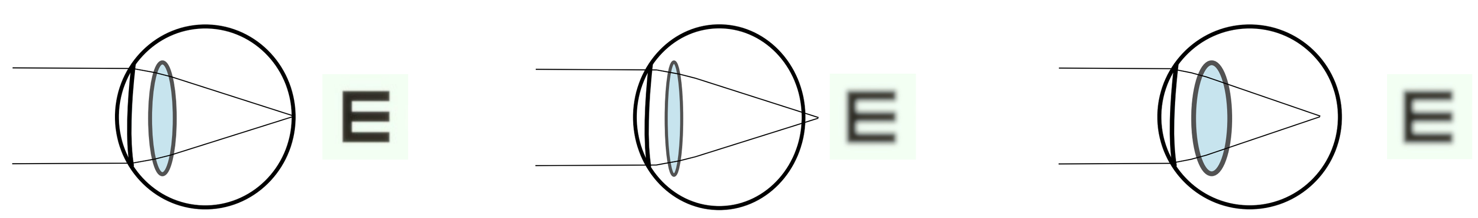
INTRODUCTION

Ocular accommodation is the process by which the eye dynamically adjusts the power of the crystalline lens to maintain a sharp retinal image at varying viewing distances.

To keep the image in focus, the visual system requires feedback about both the magnitude of blur and the direction. However, retinal blur alone is an even-error cue, appearing identical whether the eye is over- or under-accommodated.

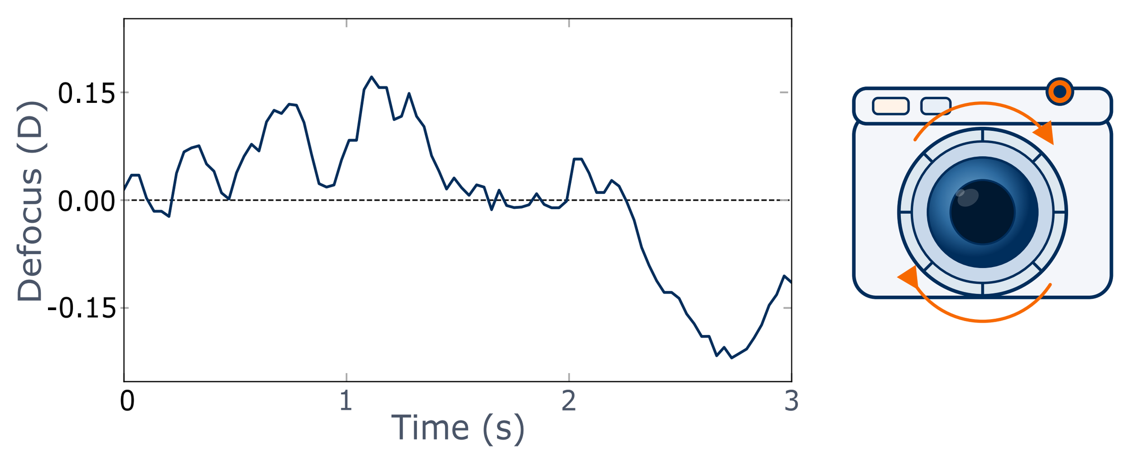


Accurate Accommodation *Under-accommodation* *Over-accommodation*

The visual system must therefore rely on an additional odd-error signal whose signature changes depending on the sign of the accommodative error. Accommodative microfluctuations (MFs) have been proposed as one such odd-error signal.

BACKGROUND: ACCOMMODATIVE MICROFLUCTUATIONS

Microfluctuations are small temporal oscillations in lens power present even during steady fixation. They consist of two main components: a low-frequency component (LFC, <0.6 Hz) and a high-frequency component (HFC, 1-2 Hz).



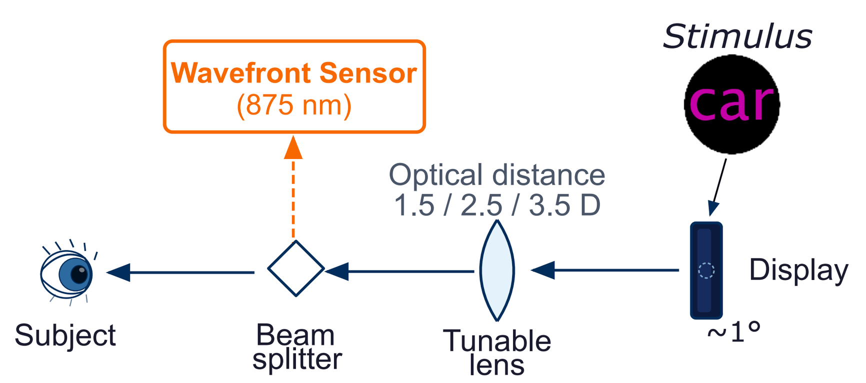
Defocus during steady fixation. Microfluctuations may act like small exploratory focus adjustments that help determine the correct direction of focus.

The sensitivity of LFC to viewing conditions suggests that the visual system may increase microfluctuations as a search strategy when directional error signals are diminished e.g., **when the light spectrum is more narrowband (saturated color)**.

EXPERIMENTAL DESIGN

Participants viewed small (~1°) three-letter words foveally at three optical distances.

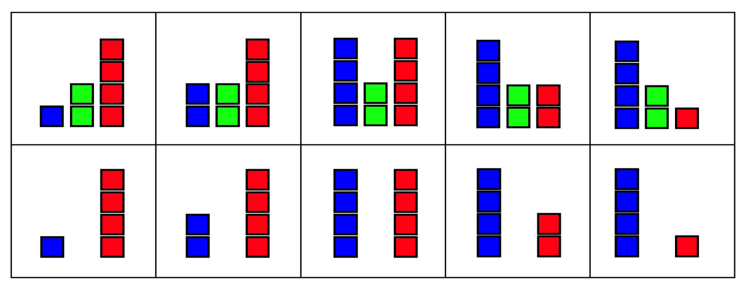
The spectral composition was varied by manipulating the red/blue luminance ratio of narrowband display primaries across 12 conditions.



Apparatus

Distances	1.5 D, 2.5 D, 3.5 D
Spectra	10 spectral conditions
Trials	180 per subject

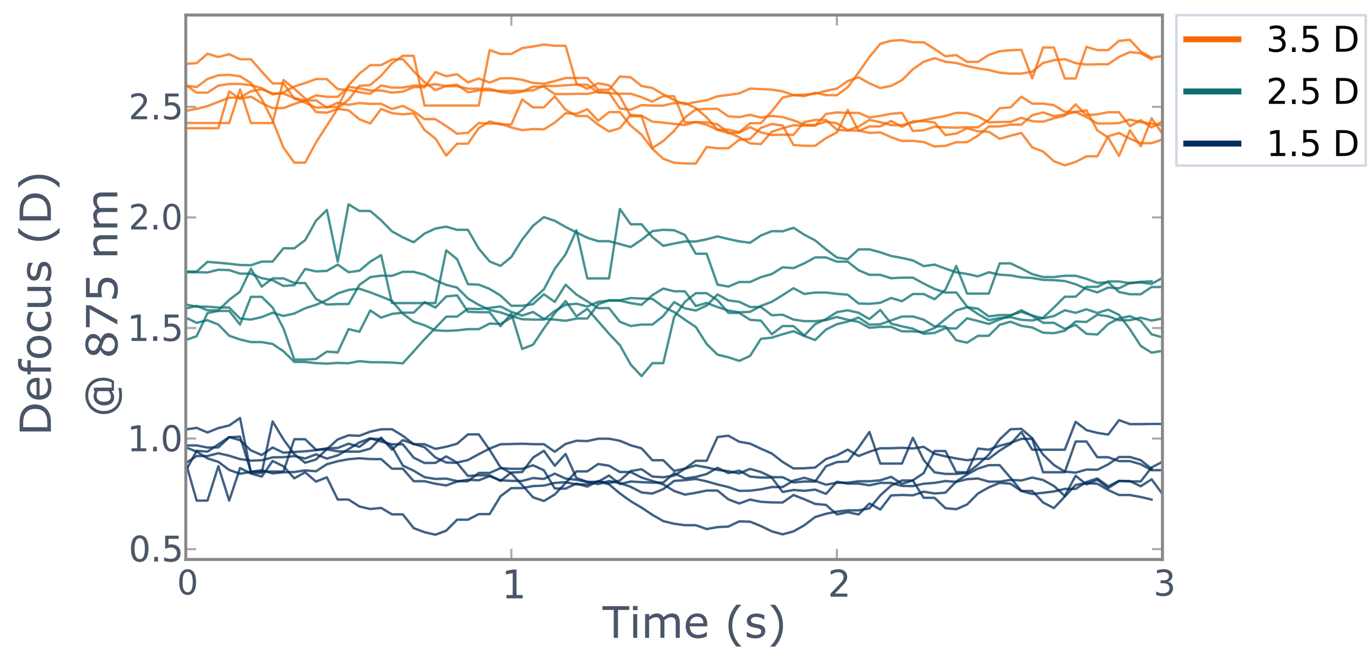
Experimental Conditions: 6 trials per distance per color condition.



The 10 spectral conditions. Each colored square represents 0.1cd/m² of luminance.

QUANTIFYING MICROFLUCTUATIONS

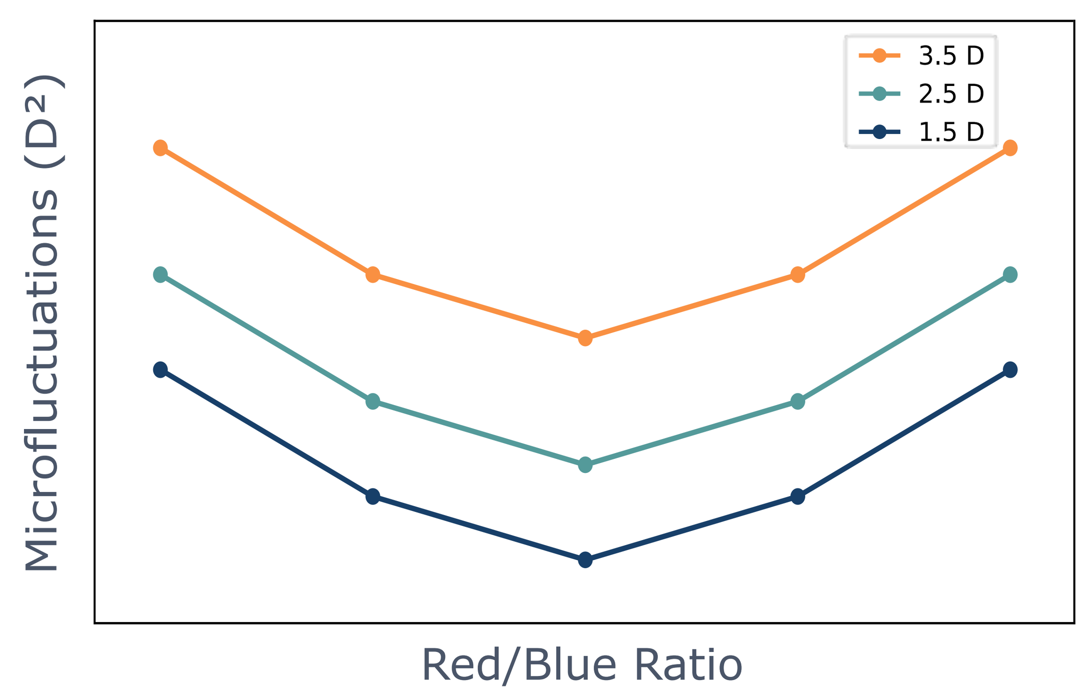
- Defocus time series was calculated for each trial from Zernike coefficients (Z4) expressed in diopters.



Example accommodation traces across three distances (orange = 3.5 D, teal = 2.5 D, navy = 1.5 D).

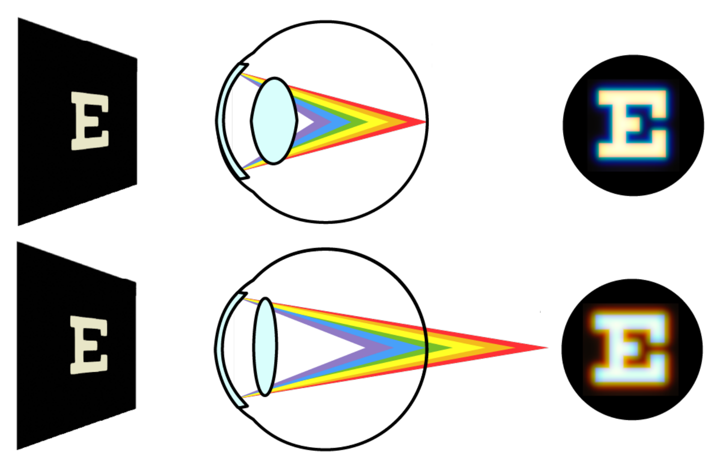
- Power spectra were computed using Fourier transform to quantify temporal fluctuations in accommodation.
- Power in low-frequency components was averaged across trials and participants for each spectral condition & accommodative demand.

Expected Microfluctuations Power Pattern



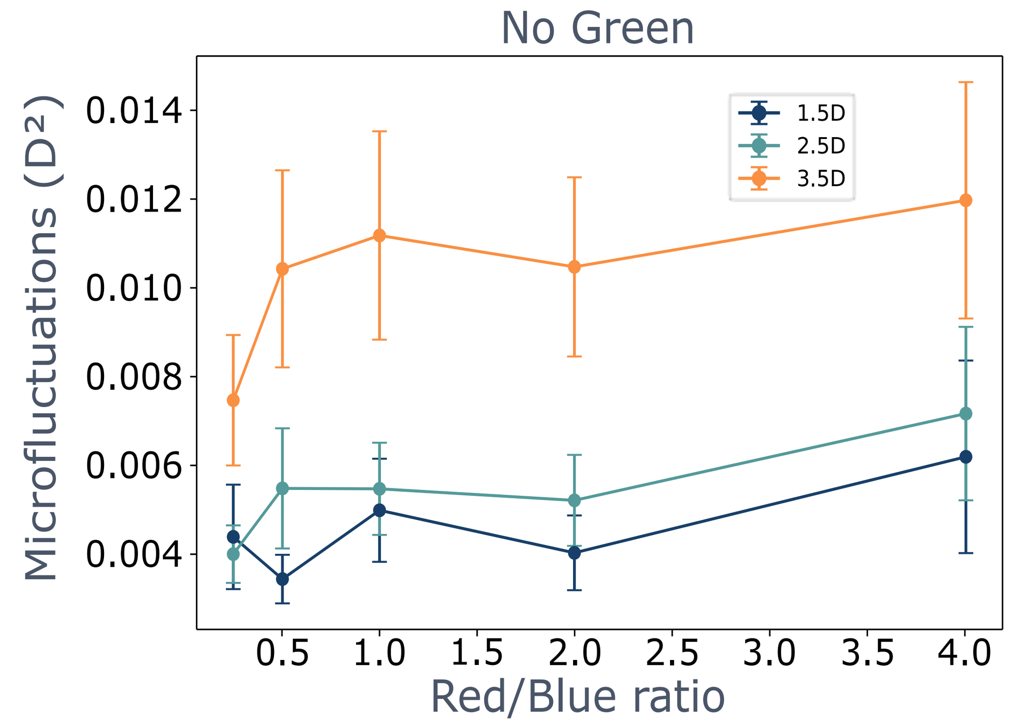
Broadband light provides reliable directional cues for accommodation, whereas at spectral extremes this information is reduced.

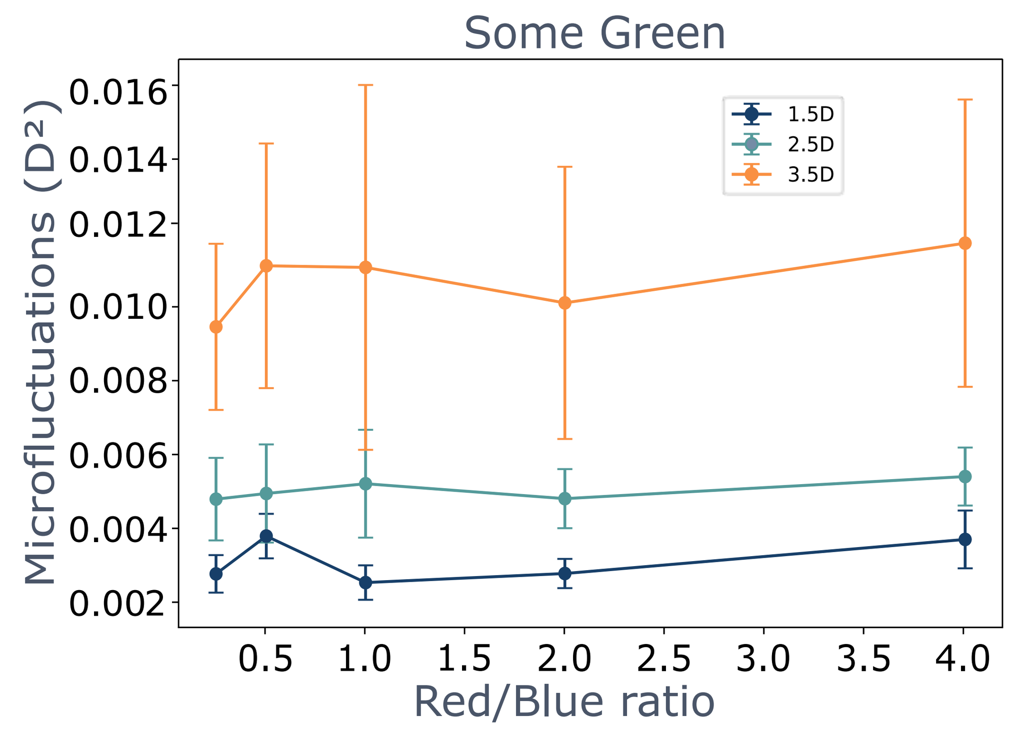
If microfluctuations act as a search signal, their power should increase at the extremes, producing a U-shaped relationship with red/blue ratio.



Wavelength-dependent image blur from LCA, provides directional signal for accommodation. Without it accommodation is more difficult which might increase microfluctuations.

RESULTS





Powen in LFC of microfluctuations vs ratio of intenisty of red and blue primaries.

Effect of Target Distance ($F(2, 180) = 4.99$, $p < 0.01$)
LFC power scaled with accommodative demand, consistent with prior findings that microfluctuations increase as the task of maintaining focus becomes more demanding.

Effect of Spectral Condition ($F(9, 180) = 0.29$, $p = 0.98$)
Chromatic content did not modulate LFC power. The predicted U-shaped relationship between red/blue ratio and LFC was absent across all distance conditions.

Interaction ($F(18, 180) = 0.20$, $p = 1.0$)
The effect of target distance on LFC power did not depend on spectral condition.

CONCLUSION

Under steady-state conditions, microfluctuations are more strongly associated with accommodative demand than with spectral content of the stimulus.

LFC power increased significantly with accommodative demand, replicating prior findings linking microfluctuations to accommodative effort.

For a more direct test, future work will perturb the natural microfluctuation signal by introducing external optical vergence noise at frequencies matched to the LFC band.

REFERENCES

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