

Reporting Summary

Nature Portfolio wishes to improve the reproducibility of the work that we publish. This form provides structure for consistency and transparency in reporting. For further information on Nature Portfolio policies, see our [Editorial Policies](#) and the [Editorial Policy Checklist](#).

Statistics

For all statistical analyses, confirm that the following items are present in the figure legend, table legend, main text, or Methods section.

n/a Confirmed

- | | | |
|-------------------------------------|-------------------------------------|--|
| ☐ | ☒ | The exact sample size (n) for each experimental group/condition, given as a discrete number and unit of measurement |
| ☐ | ☒ | A statement on whether measurements were taken from distinct samples or whether the same sample was measured repeatedly |
| ☐ | ☒ | The statistical test(s) used AND whether they are one- or two-sided
<i>Only common tests should be described solely by name; describe more complex techniques in the Methods section.</i> |
| ☒ | ☐ | A description of all covariates tested |
| ☐ | ☒ | A description of any assumptions or corrections, such as tests of normality and adjustment for multiple comparisons |
| ☐ | ☒ | A full description of the statistical parameters including central tendency (e.g. means) or other basic estimates (e.g. regression coefficient) AND variation (e.g. standard deviation) or associated estimates of uncertainty (e.g. confidence intervals) |
| ☐ | ☒ | For null hypothesis testing, the test statistic (e.g. F , t , r) with confidence intervals, effect sizes, degrees of freedom and P value noted
<i>Give P values as exact values whenever suitable.</i> |
| ☒ | ☐ | For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings |
| ☒ | ☐ | For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes |
| ☐ | ☒ | Estimates of effect sizes (e.g. Cohen's d , Pearson's r), indicating how they were calculated |

Our web collection on [statistics for biologists](#) contains articles on many of the points above.

Software and code

Policy information about [availability of computer code](#)

Data collection Data were collected using custom experiment code in MATLAB (version R2014b) with Psychophysics Toolbox (version 3.0).

Data analysis Data were analyzed using JASP (Version 0.18.1) and custom code written in MATLAB (version R2020b).

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Portfolio [guidelines for submitting code & software](#) for further information.

Data

Policy information about [availability of data](#)

All manuscripts must include a [data availability statement](#). This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A description of any restrictions on data availability
- For clinical datasets or third party data, please ensure that the statement adheres to our [policy](#)

The psychophysical data that support the findings of this study are available in Supplementary Data. The modeling data used to produce the figures were generated via the MATLAB code of the model simulation, which is available in Supplementary Software.

Research involving human participants, their data, or biological material

Policy information about studies with [human participants or human data](#). See also policy information about [sex, gender \(identity/presentation\), and sexual orientation](#) and [race, ethnicity and racism](#).

Reporting on sex and gender	The sex characteristics of the participants in the psychophysical experiment were as follows: 12 men and 10 women. Participants' sex were determined based on self-report.
Reporting on race, ethnicity, or other socially relevant groupings	All participants were Chinese adults based on investigator's observation. All ethical regulations relevant to human research participants were followed.
Population characteristics	See "Behavioural & social sciences study design".
Recruitment	The participants in the psychophysical experiment were randomly recruited via online advertising as long as they satisfied relevant criteria.
Ethics oversight	The Research Ethics Board of Zhejiang University.

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☐ Life sciences ☒ Behavioural & social sciences ☐ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Behavioural & social sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	The study obtained quantitative psychophysical data with a within-subjects, repeated measures experimental design.
Research sample	Twelve male and ten female observers (mean age, 20.6 years; range, 18–24 years) participated in the psychophysical experiment. All observers were students at Zhejiang University, and had normal or corrected-to-normal visual acuity and normal stereopsis, and were naïve as to the purpose of the experiment.
Sampling strategy	The participants were randomly recruited. The sample size is determined based on preliminary experiments and relevant vision literature (typically test 10-25 observers).
Data collection	The experiment was conducted in a quiet testing room. During experimental blocks, the only light source was the computer monitor. The experimenter was present to give instructions and throughout training and checked on the observer between testing blocks. Visual stimuli were generated using MATLAB R2014a (MathWorks, Natick, MA, USA) with the Psychophysics Toolbox 3.0 on a Windows computer, and presented on a linearized CRT monitor (22" Hewlett-Packard P1230 or 17" Sony G220; 1024 × 768 resolution; 100 Hz refresh rate; 44.5 cd/m ² mean luminance; 60 cm viewing distance). Observers viewed pairs of monocular stimuli dichoptically through a mirror-stereoscope with the head comfortably stabilized by a chin rest. Observers completed all three experimental conditions in a balanced order over three consecutive days, and each condition was separated by at least 6 h and typically by one day.
Timing	The initial phase of data collection started on June 2020 and completed on September 2020, and the subsequent phase started on September 2024 and completed on in November 2024.
Data exclusions	No data were excluded.
Non-participation	No participants dropped out or declined to participate.
Randomization	The order of three experimental conditions and two stimulus orientations was counterbalanced across participants.

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study
☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
☒	☐ Palaeontology and archaeology
☒	☐ Animals and other organisms
☒	☐ Clinical data
☒	☐ Dual use research of concern
☒	☐ Plants

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging