

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
Only common tests should be described solely by name; describe more complex techniques in the Methods section.
- ☒ ☐ 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
Give P values as exact values whenever suitable.
- ☐ ☒ 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

-Intan recording software is available at <https://intantech.com/downloads.html?tabSelect=Software&yPos=0>
-Psychtoolbox for visual stimulation administration is available at <http://psychtoolbox.org/>

Data analysis

- Mountainsort(v4) for spike sorting is available at https://github.com/magland/ml_ms4alg
- LDA decoders are available with MATLAB (2023b Linux OS) function fitcdiscr. Linear mixed effect, multiple linear regressions were performed with MATLAB function fitlm, fitlme.
- Customized code for temporal components fitting, quantification of representational drift, longitudinal population representation, chronic decoding, explaining neural codes from behaviors, and tracking same units were done in MATLAB and is available at https://github.com/XieLuanLab/temporal_code_stability
- To test different in correlation coefficient, MSTATS toolbox(v2.0) was used <https://www.mathworks.com/matlabcentral/fileexchange/47235-mstats-a-random-collection-of-statistical-functions>.
- UMAP(v4.2) for dimension reduction is available at <https://www.mathworks.com/matlabcentral/fileexchange/71902-uniform-manifold-approximation-and-projection-umap>
- CellExplorer(v1.2) for ACG, CCG, cell type classification, is available at <https://cellexplorer.org/>
- Jitter corrected CCG(v1.0) is available at https://github.com/jiaxx/modular_network
- Shuffle corrected spike triggered population activity(v8d3cef9) is available at https://github.com/VeronikaKoren/struct_pop_public
- Dense neural network (v0.1.2) used for validation of labelling consistency is available at https://github.com/KordingLab/Neural_Decoding
- DeeplabCut(v2.0+) for animal pose labelling is available at <https://github.com/DeepLabCut/DeepLabCut>
- YOLO(v8) for animal pose labelling is available at <https://docs.ultralytics.com/>

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 data generated in this study are provided in the Figures/Supplementary Information/Source Data file. The processed electrophysical data, including but not limited to neuron population spiking timestamps across different trials X stimulus types X recording days are available in the figshare database under accession code <https://doi.org/10.6084/m9.figshare.28877813113>. Source data are provided with this paper.

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	N/A
Reporting on race, ethnicity, or other socially relevant groupings	N/A
Population characteristics	N/A
Recruitment	N/A
Ethics oversight	N/A

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](https://www.nature.com/documents/nr-reporting-summary-flat.pdf)

Life sciences study design

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

Sample size	Sample size was not predetermined by statistical analysis. Sample size was chosen based on species specific standards for replicability in neural recordings (n=5 mice) while minimizing research animal use.
Data exclusions	No animals were excluded. Unit inclusion criteria for individual figures was stated in the Methods and Source Data

Replication	Tracking same neurons using ultraflexible electrode arrays for studying visual representation stability have been reproduced in 5 mice in this study
Randomization	Randomization was not relevant in this study because animals were not divided into a control group and an experimental group.
Blinding	Blinding was not relevant in this study because animals were not divided into a control group and an experimental group.

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

Animals and other research organisms

Policy information about [studies involving animals](#); [ARRIVE guidelines](#) recommended for reporting animal research, and [Sex and Gender in Research](#)

Laboratory animals	n=2 adult (3-6 months old) male C57BL/6J-Tg (Thy1-GCaMP6s) GP4.3Dkim/J bred on-site and n=3 adult (3-6 months old) male C57BL/6J mice acquired from Jackson Laboratories (Bar Harbor, ME) were used in the experiments. Animals were housed in normal dark/light cycle (7a lights on, 7p lights off), with ambient temperature 68~72°F and humidity 30~70%
Wild animals	This work did not involve wild animals
Reporting on sex	To rule out the potential effect of hormone fluctuations on representational drift and given we did not record at the time scale to measure these changes, all male mice was used. Due to the usage of a single sex, no disaggregated reporting on sex was possible.
Field-collected samples	This work did not involve field-collected samples
Ethics oversight	Animal experiment protocols in this paper were approved by the Rice University IACUC under protocol 20-023

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

Plants

Seed stocks	N/A
Novel plant genotypes	N/A
Authentication	N/A