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Corresponding author(s): Zachary A. Knight

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Reporting Summary

Nature Research 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 Research policies, see Authors & Referees 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	Coulbourn Graphic State (v4.2), Inscopix nVista (v2.0), LabJack LJStreamUD (v1.7)
Data analysis	GraphPad Prism (v7.0), Inscopix Mosaic (1.7), MathWorks Matlab (vR2018a), Fiji/ImageJ (v2.0)

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/reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Research 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 list of figures that have associated raw data
- A description of any restrictions on data availability

Data that support the findings of this study are available from the corresponding author upon reasonable request.

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

Life sciences study design

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

Sample size	Statistical methods to predetermine sample size were not used. Sample sizes were based on previous studies from our lab and others.
Data exclusions	Mice for fiber photometry (>10% ΔF/F response to 3 M NaCl i.p.) and optogenetics (>100 licks during photostimulation) experiments were included based on functional validation. Recordings from microendoscope experiments were included based on the visibility of fluorescent cells.
Replication	The main findings of the paper were confirmed by multiple complementary experiments. We performed recordings and behavioral experiments with multiple animals to confirm reproducibility. All attempts at replication were successful.
Randomization	For recording experiments, trials were not randomized, but within-animal controls were used whenever possible. For behavioral experiments, mice were pseudorandomly assigned to experimental and control groups before surgery/experiment.
Blinding	Blinding was not used. All data analysis was performed automatically using Matlab with the same scripts run for each 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
☐	☒ Animals and other organisms
☒	☐ Human research participants
☒	☐ Clinical data

Methods

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

Antibodies

Antibodies used	chicken anti-GFP (Abcam ab13970, 1:1000), rat anti-RFP (ChromoTek 5f8, 1:1000), goat anti-mCherry (Acris ab0040-200, 1:1000), rabbit anti-Fos (Santa mCruz Biotech sc52, 1:500), rabbit anti-NeuN (Millipore abn78, 1:1000), Alexa Fluor 488 goat anti-chicken (Life Technologies a11039, 1:500 or 1:1000), Alexa Fluor 568 goat anti-rat (Life Technologies a11077, 1:1000), Alexa Fluor 568 goat anti-rabbit (Life Technologies a11011, 1:500 or 1:1000), Alexa Fluor donkey anti-goat (Life Technologies a11057, 1:1000).
Validation	Antibodies were validated for use in mouse brain sections in pilot experiments in our lab and by the manufacturers.

Animals and other organisms

Policy information about studies involving animals; ARRIVE guidelines recommended for reporting animal research

Laboratory animals	Nos1-Ires-Cre (stock no. 017526), Avp-Ires2-Cre (stock no. 023530), Glp1r-Ires-Cre (stock no. 029283), Rosa26-lsl-Gfp-Rpl10 (stock no. 022367), and wild type (stock no. 000664) mice were obtained from the Jackson Laboratory. Ai148D mice were obtained from the Allen Institute for Brain Science and Trpv1-Gfp-2a-Dtr mice were obtained from Mark Hoon at the National Institutes of Health. Nxph4-2a-Cre mice were generated by CRISPR/Cas9-mediated homologous recombination and maintained on a mixed FVB/C57Bl/6J background. Adult mice (>6 weeks old) of both sexes were used for experiments.
Wild animals	No wild animals were used.
Field-collected samples	No field-collected samples were used.
Ethics oversight	Experimental protocols were approved by the University of California, San Francisco IACUC following the NIH Guide for the Care and Use of Laboratory Animals.

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