

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](#).

Statistical parameters

When statistical analyses are reported, confirm that the following items are present in the relevant location (e.g. 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
- An indication of 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 statistics 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
- Clearly defined error bars
State explicitly what error bars represent (e.g. SD, SE, CI)

Our web collection on [statistics for biologists](#) may be useful.

Software and code

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

Data collection Matlab, Vidrio technologies ScanImage, Molecular Devices PClamp, Labview

Data analysis ImageJ (Version 1.47), Cell Sort written in Matlab (2017a,b) and custom software written in MATLAB (2017a,b)

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 upon request. 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

The data and custom code that support the findings of this study are available from the corresponding author upon reasonable request.

Field-specific reporting

Please select 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/authors/policies/ReportingSummary-flat.pdf](https://www.nature.com/authors/policies/ReportingSummary-flat.pdf)

Life sciences study design

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

Sample size	No statistical methods were used to predetermine sample sizes. Sample sizes were based on reliably measuring experimental parameters while remaining in compliance with ethical guidelines to minimize the number of animals used. Spearman's Rank tests, T tests, repeated measures ANOVA, Tukey's post-test with Bonferroni Correction, Bootstrap tests, Shuffle tests and Wilcoxon rank tests were used to test for statistical significance when appropriate and all statistical tests were two-sided unless stated otherwise.
Data exclusions	All inclusion/exclusion criteria were established independently and prior to analysis of effect sizes. For imaging experiments, mice were excluded from analysis if no GCaMP expression was observed or if motion artifact was too large. Only mice that were able to perform the virtual reality tasks detailed below (reward rate >~1 reward/min) were included in this study because behavioral periods of poorly behaving mice were difficult to interpret. Selection for well defined behavioral periods was performed as follows to focus on reproducible and interpretable behavior periods across mice. Running periods were defined when mouse movement velocity along the virtual track first increased above 10 cm/sec and maintained at least 5 cm/sec for at least 25 cm of movement along the track (excluding transition zones). Wait trials were included if the mouse stopped at the door location and maintained velocity below threshold (5.2 or 6.9 cm/sec) for the entire 6 second wait period and then began running (velocity >5.2 or 6.9 cm/sec) within 3 seconds from the door opening.
Replication	Experimental results were based on neural activity patterns and mouse behavior during tasks. Multiple mice (n) were used for every experiment and observations of similar results across mice were used to infer replication. All attempts at replication were successful.
Randomization	Randomization was not required because this study did not allocate different mouse experimental groups.
Blinding	Blinding was not required because this study did not allocate different mouse experimental groups.

Reporting for specific materials, systems and methods

Materials & experimental systems

- n/a | Involved in the study
- Unique biological materials
- Antibodies
- Eukaryotic cell lines
- Palaeontology
- Animals and other organisms
- Human research participants

Methods

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

Animals and other organisms

Policy information about [studies involving animals](#); [ARRIVE guidelines](#) recommended for reporting animal research

Laboratory animals	male C57-BL6 mice (~p70).
Wild animals	This study did not involve wild animals.
Field-collected samples	This study did not involve samples collected from the field.