nature portfolio

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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	Optogenetic self-stimulation and Intravenous methamphetamine self-administration data: Commercialized Software from AniLab; Fiber photometry data: commercialized software from ThinkerTech; Real-time place preference data: customed code from MATLAB; Whole-cell recording data: commercialized Software Clampex 10.5; Histological image data: commercialized software OlyVIA; commercialized software TissueFAXS; open source software ImageJ.
Data analysis	MATLAB 2021 ,and Prism 9.1.0.

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 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 raw data used in this paper are available from the corresponding author upon request.

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	This information has not been collected
Reporting on race, ethnicity, or other socially relevant groupings	This information has not been collected
Population characteristics	This information has not been collected
Recruitment	This information has not been collected
Ethics oversight	This information has not been collected

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

Life sciences study design

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

Sample size	Behavioral data for each condition were sampled from 5 to 15 rats or mice. For fiber photometry recordings, the sample sizes were N =7 to 15 mice per group. Western blot data for each condition were sampled from brain tissue of 4 to 8 rats or mice. Immunohistochemical data for each condition were sampled from tissue sections of 3 to 9 mice. These sample sizes align with those reported in previous studies (PMID: 32679036, PMID: 0361366, PMID: 26840481, PMID: 36753418, PMID: 36028570).
Data exclusions	In the social rank test, 19 out of 214 pairs of animals were excluded due to ambiguous social rank, defined as neither side achieving a win rate of over 60% in the last two days of the tube test. In the experiments involving intravenous catheter implantation, such as METH self-administration and some fiber photometry experiments, 12 out of 272 animals were excluded due to death from infection or blood loss, and 41 were excluded due to issues with the catheter, such as leakage or obstruction. For the fiber photometry and optogenetic manipulation experiments, 9 out of 186 animals were excluded due to incorrect fiber tip placement.
Replication	Experiments were performed with sufficient animals per group (n>4) to demonstrate statistical significance. For histological experiments, at least repeated in three animals. All attempts at replication were successful.
Randomization	Animals were randomly assigned into control or different experimental groups.
Blinding	We were blinded for the immunofluorescence, Western blot, and some fiber photometry recordings, but not for the behavioral experiments and data analysis.

Behavioural & social sciences study design

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

Study description	

Research sample	
Sampling strategy	
Data collection	
Timing	
Data exclusions	
Non-participation	
Randomization	

Ecological, evolutionary & environmental sciences study design

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

Study description	
Research sample	
Sampling strategy	
Data collection	
Timing and spatial scale	
Data exclusions	
Reproducibility	
Randomization	
Blinding	

Did the study involve field work? ☐ Yes ☐ No

Field work, collection and transport

Field conditions	
Location	
Access & import/export	
Disturbance	

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

Antibodies

Antibodies used

Rabbit anti-tyrosine hydroxylase (Millipore, Cat# AB152; RRID:AB_390204), Goat anti-rabbit Alexa Fluor 488 (Thermo Fisher Scientific, Cat# A-11034; RRID:AB_2576217), Anti-Dopamine Transporter (Millipore, Cat# AB2231; RRID:AB_1586991), Anti-Phospho-Dopamine Transporter (Thr53) (Thermo Fisher Scientific, Cat# PA5-35414; RRID:AB_2552724), Anti-ERK1/2 (Cell Signaling, Cat# 4695S; RRID:AB_390779), Anti-Phospho-ERK1/2 (Cell Signaling, Cat# 4370S; RRID:AB_2315112), Anti-VMAT2 (Thermo Fisher Scientific, Cat# PA5-22864; RRID:AB_11154073), Anti-Tyrosine Hydroxylase (Thermo Fisher Scientific, Cat# PA5-85356; RRID:AB_2792498), and Anti-Phospho-Tyrosine Hydroxylase (Ser40) (Thermo Fisher Scientific, Cat# PA5-17799; RRID:AB_10977526).

Validation

(1) Rabbit anti-tyrosine hydroxylase (Millipore, Cat# AB152; RRID:AB_390204)
Description: This antibody detects the level of tyrosine hydroxylase (TH) and has been published and validated for use in ELISA, IF, IH, IH(P), IP, and WB. It reacts with most mammalian and many non-mammalian species, including human, feline, ferret, rat, squid, mouse, and more. It is a useful marker for dopaminergic and noradrenergic neurons.
Species Reactivity: Human, feline, ferret, rat, squid, mouse, and others.
Reference: PMID: 29398114.
(2) Goat anti-rabbit Alexa Fluor 488 (Thermo Fisher Scientific, Cat# A-11034; RRID:AB_2576217)
Description: This secondary antibody is highly cross-adsorbed and conjugated with Alexa Fluor 488, a bright green-fluorescent dye. It is designed for use in immunofluorescence, flow cytometry, and other applications where green fluorescence detection is required.
Species Reactivity: Rabbit IgG.
Reference: PMID: 30123456.
(3) Anti-Dopamine Transporter (Millipore, Cat# AB2231; RRID:AB_1586991)
Description: This antibody is specific for the dopamine transporter and has been validated for use in immunohistochemistry, western blot, and other applications. It is useful for studying dopamine transport and related neurological processes.
Species Reactivity: Human, mouse, rat, and non-human primate.
Reference: PMID: 28072417.
(4) Anti-Phospho-Dopamine Transporter (Thr53) (Thermo Fisher Scientific, Cat# PA5-35414; RRID:AB_2552724)
Description: This antibody specifically recognizes the phosphorylated form of the dopamine transporter at Thr53. It is suitable for western blot and immunohistochemistry applications to study the regulation of dopamine transport.
Species Reactivity: Human, mouse, rat.
Reference: PMID: 30936473.
(5) Anti-ERK1/2 (Cell Signaling, Cat# 4695S; RRID:AB_390779)
Description: This antibody detects endogenous levels of ERK1 and ERK2. It is validated for use in western blot, immunohistochemistry, and other applications to study the MAPK signaling pathway.
Species Reactivity: Human, Mouse, Rat, Hamster, Monkey.
Reference: PMID: 39910202.
(6) Anti-Phospho-ERK1/2 (Cell Signaling, Cat# 4370S; RRID:AB_2315112)
Description: This antibody specifically recognizes the phosphorylated forms of ERK1 and ERK2 at Thr202/Tyr204. It is widely used in western blot and immunohistochemistry to study the activation of the MAPK signaling pathway.
Species Reactivity: Human, mouse, rat.
Reference: PMID: 39910202.
(7) Anti-VMAT2 (Thermo Fisher Scientific, Cat# PA5-22864; RRID:AB_11154073)
Description: This antibody is specific for vesicular monoamine transporter 2 (VMAT2) and is validated for use in western blot, immunohistochemistry, and other applications. It is useful for studying monoamine neurotransmission.
Species Reactivity: Human, mouse, rat.
Reference: PMID: 31982500.
(8) Anti-Tyrosine Hydroxylase (Thermo Fisher Scientific, Cat# PA5-85356; RRID:AB_2792498)
Description: This antibody detects tyrosine hydroxylase and is validated for use in western blot, immunohistochemistry, and other applications. It is suitable for studying catecholamine biosynthesis.
Species Reactivity: Human, mouse, rat.
Reference: PMID: 39780483.
(9) Anti-Phospho-Tyrosine Hydroxylase (Ser40) (Thermo Fisher Scientific, Cat# PA5-17799; RRID:AB_10977526)
Description: This antibody specifically recognizes the phosphorylated form of tyrosine hydroxylase at Ser40. It is suitable for western blot and immunohistochemistry to study the regulation of catecholamine biosynthesis.
Species Reactivity: Human, mouse, rat.
Reference: https://www.thermofisher.cn/cn/zh/antibody/product/Phospho-Tyrosine-Hydroxylase-Ser40-Antibody-Polyclonal/PA5-17799

Eukaryotic cell lines

Policy information about cell lines and Sex and Gender in Research

Cell line source(s)	
Authentication	
Mycoplasma contamination	
Commonly misidentified lines (See ICLAC register)	

Palaeontology and Archaeology

Specimen provenance	
Specimen deposition	
Dating methods	

☐ Tick this box to confirm that the raw and calibrated dates are available in the paper or in Supplementary Information.

Ethics oversight	

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

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	Wild-type Sprague-Dawley rats, C57BL/6j mice (Charles River Laboratories, Hangzhou, China), DAT-IRES-Cre transgenic mice (JAX Stock No: 006660) and Ai14 transgenic mice (JAX Stock No: 007908). All animals used in the formal experiments were 6-14 weeks old, housed in pairs per cage, under a standard 12-hour light/dark cycle (lights on at 8:00 A.M.), at a constant temperature of 23 ± 1°C, with humidity maintained at 50%-60%, and with food and water available ad libitum.
Wild animals	No wild animals were used in this study.
Reporting on sex	Both sex mice were used in this study. Sex-based analyses are displayed in Extended Data Fig. 9 and 10.
Field-collected samples	No field-collected samples were used in this research.
Ethics oversight	All experimental procedures were conducted following protocols approved by the Animal Care and Use Committees at the Shenzhen Institute of Advanced Technology (SIAT), Chinese Academy of Sciences (CAS)

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

Clinical data

Policy information about clinical studies

All manuscripts should comply with the ICMJE guidelines for publication of clinical research and a completed CONSORT checklist must be included with all submissions.

Clinical trial registration	
Study protocol	
Data collection	
Outcomes	

Dual use research of concern

Policy information about dual use research of concern

Hazards

Could the accidental, deliberate or reckless misuse of agents or technologies generated in the work, or the application of information presented in the manuscript, pose a threat to:

No	Yes	
☐	☐	Public health
☐	☐	National security
☐	☐	Crops and/or livestock
☐	☐	Ecosystems
☐	☐	Any other significant area

Experiments of concern

Does the work involve any of these experiments of concern:

No	Yes	
☐	☐	Demonstrate how to render a vaccine ineffective
☐	☐	Confer resistance to therapeutically useful antibiotics or antiviral agents
☐	☐	Enhance the virulence of a pathogen or render a nonpathogen virulent
☐	☐	Increase transmissibility of a pathogen
☐	☐	Alter the host range of a pathogen
☐	☐	Enable evasion of diagnostic/detection modalities
☐	☐	Enable the weaponization of a biological agent or toxin
☐	☐	Any other potentially harmful combination of experiments and agents

Plants

Seed stocks

Novel plant genotypes

Authentication

ChIP-seq

Data deposition

☐ Confirm that both raw and final processed data have been deposited in a public database such as GEO.

☐ Confirm that you have deposited or provided access to graph files (e.g. BED files) for the called peaks.

Data access links
May remain private before publication.

Files in database submission

Genome browser session
(e.g. UCSC)

Methodology

Replicates

Sequencing depth

Antibodies

Peak calling parameters

Data quality

Software

Flow Cytometry

Plots

Confirm that:

☐ The axis labels state the marker and fluorochrome used (e.g. CD4-FITC).

☐ The axis scales are clearly visible. Include numbers along axes only for bottom left plot of group (a 'group' is an analysis of identical markers).

☐ All plots are contour plots with outliers or pseudocolor plots.

☐ A numerical value for number of cells or percentage (with statistics) is provided.

Methodology

Sample preparation

Instrument

Software

Cell population abundance

Gating strategy

☐ Tick this box to confirm that a figure exemplifying the gating strategy is provided in the Supplementary Information.

Magnetic resonance imaging

Experimental design

Design type

Design specifications

Behavioral performance measures

Acquisition

Imaging type(s)

Field strength

Sequence & imaging parameters

Area of acquisition

Diffusion MRI ☐ Used ☐ Not used

Preprocessing

Preprocessing software

Normalization

Normalization template

Noise and artifact removal

Volume censoring

Statistical modeling & inference

Model type and settings

Effect(s) tested

Specify type of analysis: ☐ Whole brain ☐ ROI-based ☐ Both

Statistic type for inference

(See Eklund et al. 2016)

Correction

Models & analysis

n/a	Involved in the study
☐	☐ Functional and/or effective connectivity
☐	☐ Graph analysis
☐	☐ Multivariate modeling or predictive analysis

Functional and/or effective connectivity

Graph analysis

Multivariate modeling and predictive analysis