

Corresponding Author: Stephanie Padilla

Manuscript Number: NN-A53287

Manuscript Type: Article

Main Figures: 6

Supplementary Figures: 7

Supplementary Tables: 0

Supplementary Videos: 3

Reporting Checklist for Nature Neuroscience

This checklist is used to ensure good reporting standards and to improve the reproducibility of published results. For more information, please read [Reporting Life Sciences Research](#).

Please note that in the event of publication, it is mandatory that authors include all relevant methodological and statistical information in the manuscript.

▶ Statistics reporting, by figure

- Please specify the following information for each panel reporting quantitative data, and where each item is reported (section, e.g. Results, & paragraph number).
- Each figure legend should ideally contain an exact sample size (n) for each experimental group/condition, where n is an exact number and not a range, a clear definition of how n is defined (for example x cells from x slices from x animals from x litters, collected over x days), a description of the statistical test used, the results of the tests, any descriptive statistics and clearly defined error bars if applicable.
- For any experiments using custom statistics, please indicate the test used and stats obtained for each experiment.
- Each figure legend should include a statement of how many times the experiment shown was replicated in the lab; the details of sample collection should be sufficiently clear so that the replicability of the experiment is obvious to the reader.
- For experiments reported in the text but not in the figures, please use the paragraph number instead of the figure number.

Note: Mean and standard deviation are not appropriate on small samples, and plotting independent data points is usually more informative. When technical replicates are reported, error and significance measures reflect the experimental variability and not the variability of the biological process; it is misleading not to state this clearly.

		TEST USED		n			DESCRIPTIVE STATS (AVERAGE, VARIANCE)		P VALUE		DEGREES OF FREEDOM & F/t/z/R/ETC VALUE	
FIGURE NUMBER	WHICH TEST?	SECTION & PARAGRAPH #	EXACT VALUE	DEFINED?	SECTION & PARAGRAPH #	REPORTED?	SECTION & PARAGRAPH #	EXACT VALUE	SECTION & PARAGRAPH #	VALUE	SECTION & PARAGRAPH #	
example 1a	one-way ANOVA	Fig. legend	9, 9, 10, 15	mice from at least 3 litters/group	Methods para 8	error bars are mean +/- SEM	Fig. legend	p = 0.044	Fig. legend	F(3, 36) = 2.97	Fig. legend	
example results, para 6	unpaired t-test	Results para 6	15	slices from 10 mice	Results para 6	error bars are mean +/- SEM	Results para 6	p = 0.0006	Results para 6	t(28) = 2.808	Results para 6	
+ 1d	One-way ANOVA	Sup STATS	15,7,7 13, 6, 7	mice from at least 6 litters	Sup STATS, Fig. 1d	bars are the mean, all data points shown	fig. 1d	P < 0.0001	Sup STATS	F(5, 49) = 10.35	Sup STATS	

		TEST USED		n			DESCRIPTIVE STATS (AVERAGE, VARIANCE)		P VALUE		DEGREES OF FREEDOM & F/t/z/R/ETC VALUE	
FIGURE NUMBER	WHICH TEST?	SECTION & PARAGRAPH #	EXACT VALUE	DEFINED?	SECTION & PARAGRAPH #	REPORTED?	SECTION & PARAGRAPH #	EXACT VALUE	SECTION & PARAGRAPH #	VALUE	SECTION & PARAGRAPH #	
+ -	1e	one-way ANOVA	Sup STATS	8,7,12,8	mice from at least 3 litters	Sup STATS, Fig. 1e	bars are the mean, all data points shown	Fig. 1e	P = 0.0003	Sup STATS	F(3, 31) = 8.583	Sup STATS
+ -	1f	Paired two-tailed Student's t-test	Sup STATS	12, 10	mice, paired analysis from at least 2 litters	Sup STATS, Fig. 1f	bars are the mean, all data points shown// exact M and SD	Fig. 1f// Sup STATS	P = 0.0152, P = 0.0006	Sup STATS	t(11) = 2.871 t(9) = 5	Sup STATS
+ -	2g	Paired two-tailed Student's t-test	Sup STATS	8, 6	mice, paired analysis from at least 2 litters	Sup STATS, Fig. 2g	bars are the mean, all data points shown// exact M and SD	Fig. 2g// Sup STATS	P = 0.023 P = 0.0999	Sup STATS	t(7) = 4.674 t(5) = 2.016	Sup STATS
+ -	2h	one-way ANOVA	Sup STATS	18, 8, 10	mice from at least 2 litters	Sup STATS, Fig. 2h	bars are the mean, all data points shown	Fig. 2h	P < .0001	Sup STATS	F(2, 33) = 58.68	Sup STATS
+ -	3f	Unpaired two-tailed Student's t-test	Sup STATS	8, 10	mice from at least 2 litters	Sup STATS, Fig. 3f	bars are the mean, all data points shown// exact M and SD	Fig. 3h// Sup STATS	P = 0.0008	Sup STATS	t(16) = 4.113	Sup STATS
+ -	3g	Unpaired two-tailed Student's t-test	Sup STATS	8, 8	mice from at least 2 litters	Sup STATS, Fig. 3g	bars are the mean, all data points shown// exact M and SD	Fig. 3g// Sup STATS	P < 0.0001	Sup STATS	t(14) = 8.15	Sup STATS
+ -	3i	Unpaired two-tailed Student's t-test	Sup STATS	6, 6	mice from at least 2 litters	Sup STATS, Fig. 3i	bars are the mean, all data points shown// exact M and SD	Fig. 3i// Sup STATS	P = 0.0018	Sup STATS	t = 4.21	Sup STATS
+ -	3j	2-Way repeated measures ANOVA	Sup STATS	6, 6	mice from at least 2 litters	Fig. legend	error bars are mean +/- SEM	Sup STATS	wk 8, P < .01 wk 9, P < .05 wk 10, P < .01 wk 11, P < .001	Sup STATS	wk 8, t = 3.46 wk 9, t = 3.42 wk 10, t = 3.47 wk 11, t = 4.33	Sup STATS
+ -	3k	Unpaired two-tailed Student's t-test	Sup STATS	6, 6	mice from at least 2 litters	Sup STATS, Fig. 3k	bars are the mean, all data points shown// exact M and SD	Fig. 3k// Sup STATS	P = 0.296	Sup STATS	t(10) = 1.103	Sup STATS
+ -	6b	Paired two-tailed Student's t-test	Sup STATS	5, 3	mice, paired analysis from at least 2 litters	Sup STATS, Fig. 6b	bars are the mean, all data points shown// exact M and SD	Fig. 6b// Sup STATS	P = 0.004; P = 0.074	Sup STATS	t(4) = 5.863 t(2) = 3.463	Sup STATS
+ -	6c	Paired two-tailed Student's t-test	Sup STATS	3, 3	mice, paired analysis from at least 2 litters	Sup STATS, Fig. 6c	bars are the mean, all data points shown// exact M and SD	Fig. 6c// Sup STATS	P = 0.251; P = 0.540	Sup STATS	t(2) = 5.863 t(2) = 3.463	Sup STATS
+ -	Supplementary Fig. 2a	Unpaired two-tailed Student's t-test	Sup STATS	6, 6	mice from at least 2 litters	Sup STATS	error bars are mean +/- SEM, exact M and SD	Sup Fig. 2a, Sup STATS	P = 0.976	Sup STATS	t(10) = 0.031	Sup STATS
+ -	Supplementary Fig. 2b	one-way ANOVA	Sup STATS	23, 12, 12	Mice from at least 5 litters	Sup STATS	error bars are mean +/- SEM	Sup Fig. 2 legend	P < 0.0001	Sup STATS	F(2, 44) = 46.6	Sup STATS

+ -	Supplementary Fig. 2c	Paired two-tailed Student's t-test	Sup STATS	6	mice from at least 2 litters	Sup Fig. 2c	error bars are mean +/- SEM, exact M and SD	Sup Fig. 2c, Sup STATS	P = 0.019	Sup STATS	t(5) = 3.414	Sup STATS
+ -	supplementary Fig. 2e, f	Paired two-tailed Student's t-test	Sup STATS	9, 9	mice from at least 3 litters	Sup STATS	error bars are mean +/- SEM, exact M and SD	Sup Fig. 2 legend, Sup STATS	P < 0.0001 p = .0067	Sup STATS	t(8) = 8.90 t(8) = 3.63	Sup STATS
+ -	Supplementary Fig. 6	Unpaired two-tailed Student's t-test	Sup STATS	4, 4	mice from at least 2 litters	Sup STATS	error bars are mean +/- SEM, exact M and SD	Sup Fig. 6 legend, Sup STATS	p = .479	Sup STATS	t(6) = .754	Sup STATS

► Representative figures

1. Are any representative images shown (including Western blots and immunohistochemistry/staining) in the paper?

If so, what figure(s)?

Immunohistochemistry: Fig 2a; 3d; 3e; 3h; 4a; 4c; 4d; Extended Data Fig 4; 7
in-situ hybridization: Fig. 2b

2. For each representative image, is there a clear statement of how many times this experiment was successfully repeated and a discussion of any limitations in repeatability?

If so, where is this reported (section, paragraph #)?

See methods regarding immunohistochemistry and in-situ hybridization.

► Statistics and general methods

1. Is there a justification of the sample size?

If so, how was it justified?

Where (section, paragraph #)?

Even if no sample size calculation was performed, authors should report why the sample size is adequate to measure their effect size.

Based on preliminary studies we determined an approximate effect size and used a power calculation to estimate an approximate sample size based on either paired or no-paired groups. All comparisons are detailed in the figure legends and methods section of the manuscript.

2. Are statistical tests justified as appropriate for every figure?

Where (section, paragraph #)?

We chose statistical tests based on our experimental conditions and summarized this in a section of the methods devoted to statistics

- a. If there is a section summarizing the statistical methods in the methods, is the statistical test for each experiment clearly defined?

Yes, see the methods: STATISTICS

- b. Do the data meet the assumptions of the specific statistical test you chose (e.g. normality for a parametric test)?

Yes, see the method: STATISTICS

Where is this described (section, paragraph #)?

- c. Is there any estimate of variance within each group of data?
Is the variance similar between groups that are being statistically compared?
Where is this described (section, paragraph #)?
- d. Are tests specified as one- or two-sided?
- e. Are there adjustments for multiple comparisons?
3. Are criteria for excluding data points reported?
Was this criterion established prior to data collection?
Where is this described (section, paragraph #)?
4. Define the method of randomization used to assign subjects (or samples) to the experimental groups and to collect and process data.
If no randomization was used, state so.
Where does this appear (section, paragraph #)?
5. Is a statement of the extent to which investigator knew the group allocation during the experiment and in assessing outcome included?
If no blinding was done, state so.
Where (section, paragraph #)?
6. For experiments in live vertebrates, is a statement of compliance with ethical guidelines/regulations included?
Where (section, paragraph #)?
7. Is the species of the animals used reported?
Where (section, paragraph #)?
8. Is the strain of the animals (including background strains of KO/transgenic animals used) reported?
Where (section, paragraph #)?
9. Is the sex of the animals/subjects used reported?
Where (section, paragraph #)?
10. Is the age of the animals/subjects reported?
Where (section, paragraph #)?
11. For animals housed in a vivarium, is the light/dark cycle reported?
Where (section, paragraph #)?
- All numerical data presented include standard error of the mean variances. The F value for all ANOVA calculations are included in the methods: STATISTICS
- Yes, see the methods: STATISTICS
- All post-hoc analysis is reported in methods: STATISTICS
- Exclusion criteria are reported in the methods section for each behavioral experiment. See Methods: Behavior; food challenge, elevated plus maze and resident intruder assay.
- Randomization was considered for repeated trials and is detailed in the methods: behavior.
- For all behavior analysis, digital data files were assigned a random number and scored blindly. This information is included in the methods section: behavior.
- Yes, see methods: animals.
- Yes, see methods under 'animals', line 3.
- Yes, see methods: animals.
- Yes, see methods: animals.
- Yes, see methods: animals.
- Yes, see methods: animals.

12. For animals housed in a vivarium, is the housing group (i.e. number of animals per cage) reported?
Where (section, paragraph #)?
- Yes, see methods: animals. Note, behavior experiments were conducted on singly housed animals. Intruder mice in the resident-intruder assay were group housed as described in the Methods.
13. For behavioral experiments, is the time of day reported (e.g. light or dark cycle)?
Where (section, paragraph #)?
- Yes, see methods: behavior; food-challenge, elevated plus maze and resident-intruder assay.
14. Is the previous history of the animals/subjects (e.g. prior drug administration, surgery, behavioral testing) reported?
Where (section, paragraph #)?
- Prior to experiments, animals were group-housed with litter mates in a 12-hr light cycle room.
- a. If multiple behavioral tests were conducted in the same group of animals, is this reported?
Where (section, paragraph #)?
- All paired trials (including randomization) are detailed in methods: behavior, and in the figures and figure legends.
15. If any animals/subjects were excluded from analysis, is this reported?
Where (section, paragraph #)?
- Exclusion criteria are detailed in the methods: behavior.
- a. How were the criteria for exclusion defined?
Where is this described (section, paragraph #)?
- Exclusion criteria of animals that failed to complete the trial is described in methods: behavior for each test. Stimulation-evoked food intake was used to qualify AgRP-stim animals. It has been shown that the magnitude of food consumed in this model correlates with the number of neurons transduced. We included animals that consumed greater than or equal to 1.0 g of food 4 hr post CNO-induced stimulation.
- b. Specify reasons for any discrepancy between the number of animals at the beginning and end of the study.
Where is this described (section, paragraph #)?
- 1 animal was excluded from the elevated plus maze trial because it exited the maze prior to completing a 10-min trial.
1 animal was excluded from the food-challenge assay because it moved the food into the non shock chamber on test day.

► Reagents

1. Have antibodies been validated for use in the system under study (assay and species)?
- Yes
- a. Is antibody catalog number given?
Where does this appear (section, paragraph #)?
- Yes, see methods: histology
- b. Where were the validation data reported (citation, supplementary information, Antibodypedia)?
Where does this appear (section, paragraph #)?
- The ordering information for the antibodies used are referenced. The companies provide validation data for histological staining of fixed tissue.

2. Cell line identity

- a. Are any cell lines used in this paper listed in the database of commonly misidentified cell lines maintained by [ICLAC](#) and [NCBI Biosample](#)?

Where (section, paragraph #)?

NA

- b. If yes, include in the Methods section a scientific justification of their use--indicate here in which section and paragraph the justification can be found.

NA

- c. For each cell line, include in the Methods section a statement that specifies:

- the source of the cell lines
- have the cell lines been authenticated? If so, by which method?
- have the cell lines been tested for mycoplasma contamination?

Where (section, paragraph #)?

NA

► Data deposition

Data deposition in a public repository is mandatory for:

- a. Protein, DNA and RNA sequences
- b. Macromolecular structures
- c. Crystallographic data for small molecules
- d. Microarray data

Deposition is strongly recommended for many other datasets for which structured public repositories exist; more details on our data policy are available [here](#). We encourage the provision of other source data in supplementary information or in unstructured repositories such as [Figshare](#) and [Dryad](#).

We encourage publication of Data Descriptors (see [Scientific Data](#)) to maximize data reuse.

1. Are accession codes for deposit dates provided?

Where (section, paragraph #)?

NA

► Computer code/software

Any custom algorithm/software that is central to the methods must be supplied by the authors in a usable and readable form for readers at the time of publication. However, referees may ask for this information at any time during the review process.

1. Identify all custom software or scripts that were required to conduct the study and where in the procedures each was used.

2. If computer code was used to generate results that are central to the paper's conclusions, include a statement in the Methods section under "**Code availability**" to indicate whether and how the code can be accessed. Include version information as necessary and any restrictions on availability.

▶ Human subjects

1. Which IRB approved the protocol?
Where is this stated (section, paragraph #)?
2. Is demographic information on all subjects provided?
Where (section, paragraph #)?
3. Is the number of human subjects, their age and sex clearly defined?
Where (section, paragraph #)?
4. Are the inclusion and exclusion criteria (if any) clearly specified?
Where (section, paragraph #)?
5. How well were the groups matched?
Where is this information described (section, paragraph #)?
6. Is a statement included confirming that informed consent was obtained from all subjects?
Where (section, paragraph #)?
7. For publication of patient photos, is a statement included confirming that consent to publish was obtained?
Where (section, paragraph #)?

▶ fMRI studies

For papers reporting functional imaging (fMRI) results please ensure that these minimal reporting guidelines are met and that all this information is clearly provided in the methods:

1. Were any subjects scanned but then rejected for the analysis after the data was collected?
 - a. If yes, is the number rejected and reasons for rejection described?
Where (section, paragraph #)?
2. Is the number of blocks, trials or experimental units per session and/or subjects specified?
Where (section, paragraph #)?
3. Is the length of each trial and interval between trials specified?

4. Is a blocked, event-related, or mixed design being used? If applicable, please specify the block length or how the event-related or mixed design was optimized.
5. Is the task design clearly described?
Where (section, paragraph #)?
6. How was behavioral performance measured?
7. Is an ANOVA or factorial design being used?
8. For data acquisition, is a whole brain scan used?
If not, state area of acquisition.
 - a. How was this region determined?
9. Is the field strength (in Tesla) of the MRI system stated?
 - a. Is the pulse sequence type (gradient/spin echo, EPI/spiral) stated?
 - b. Are the field-of-view, matrix size, slice thickness, and TE/TR/flip angle clearly stated?
10. Are the software and specific parameters (model/functions, smoothing kernel size if applicable, etc.) used for data processing and pre-processing clearly stated?
11. Is the coordinate space for the anatomical/functional imaging data clearly defined as subject/native space or standardized stereotaxic space, e.g., original Talairach, MNI305, ICBM152, etc? Where (section, paragraph #)?
12. If there was data normalization/standardization to a specific space template, are the type of transformation (linear vs. nonlinear) used and image types being transformed clearly described? Where (section, paragraph #)?
13. How were anatomical locations determined, e.g., via an automated labeling algorithm (AAL), standardized coordinate database (Talairach daemon), probabilistic atlases, etc.?
14. Were any additional regressors (behavioral covariates, motion etc) used?
15. Is the contrast construction clearly defined?
16. Is a mixed/random effects or fixed inference used?

- a. If fixed effects inference used, is this justified?
17. Were repeated measures used (multiple measurements per subject)?
- a. If so, are the method to account for within subject correlation and the assumptions made about variance clearly stated?
18. If the threshold used for inference and visualization in figures varies, is this clearly stated?
19. Are statistical inferences corrected for multiple comparisons?
- a. If not, is this labeled as uncorrected?
20. Are the results based on an ROI (region of interest) analysis?
- a. If so, is the rationale clearly described?
- b. How were the ROI's defined (functional vs anatomical localization)?
21. Is there correction for multiple comparisons within each voxel?
22. For cluster-wise significance, is the cluster-defining threshold and the corrected significance level defined?

► Additional comments

Additional Comments