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.

<table>
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<th>TEST USED</th>
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Nature Neuroscience: doi:10.1038/nn.3884
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| Sup. 6b | Wilcoxon Rank-sum Test | Online Methods Statistics | 195, 324 Number of cells in VR Random-Pillar and VR Systematic-Pillar respectively | Fig. 3 legend | Mean +/- SEM | Fig. legend | 0.44 | Fig. legend | $z = -0.77$
| Sup. 6c | Wilcoxon Rank-sum Test | Online Methods Statistics | 282,719 Number of cells in VR Systematic-Pillar (with at least 100 spikes in each session half) and VR random respectively | Fig. 2 legend, Sup. Fig. 6 legend | Mean +/- SEM | Fig. legend | 2.4e-3 | Fig. legend | $z = 3.04$
| Sup. 6c | Wilcoxon Rank-sum Test | Online Methods Statistics | 282, 1066 Number of cells in VR Systematic-Pillar (with at least 100 spikes in each session half) and RW respectively | Fig. 2 legend, Sup. Fig. 6 legend | Mean +/- SEM | Fig. legend | 1.8e-18 | Fig. legend | $z = -8.77$
| Sup. 8c | Wilcoxon Signed-Rank Test | Online Methods Statistics | 431 Number of multi-arm selective arm pairs in the three-pillar task | Sup. Fig. 8 legend, Fig. 4d legend | Mean +/- SEM | Fig. legend | 1.5e-031 | Fig. legend | $z = -11.69$
| Sup. 9a | Wilcoxon Rank-sum Test | Online Methods Statistics | 1064, 911 Number of cells with at least five motifs in RW and VR, respectively | Fig. 5e legend | Mean +/- SEM | Fig. legend | 7.7e-10 | Fig. legend | $z = -6.15$
| Sup. 9b | Wilcoxon Rank-sum Test | Online Methods Statistics | 1064, 911 Number of cells with at least five motifs in RW and VR, respectively | Fig. 5e legend | Mean +/- SEM | Fig. legend | 6.1e-021 | Fig. legend | $z = -9.39$
| Sup. 9c | t-test for correlation coefficient | Online Methods Statistics | 1064 Number of cell with at least five motifs in RW | Fig. 5e legend | correlation coefficient | Fig. legend | 4.1e-65 | Fig. legend | $r = 0.54$
| Sup. 9c | t-test for correlation coefficient | Online Methods Statistics | 911 Number of cell with at least five motifs in VR | Fig. 5e legend | correlation coefficient | Fig. legend | 1.2e-28 | Fig. legend | $r = 0.41$
| Sup. 9d | t-test for correlation coefficient | Online Methods Statistics | 1064 Number of cell with at least five motifs in RW | Fig. 5e legend | correlation coefficient | Fig. legend | 4.2e-17 | Fig. legend | $r = 0.28$
| Sup. 9d | t-test for correlation coefficient | Online Methods Statistics | 911 Number of cell with at least five motifs in VR | Fig. 5e legend | correlation coefficient | Fig. legend | 6.5e-12 | Fig. legend | $r = 0.26$
| Sup. 9e | Wilcoxon Rank-sum Test | Online Methods Statistics | 1064, 911 Number of cells with at least five motifs in RW and VR, respectively | Fig. 5e legend | Mean +/- SEM | Fig. legend | 9.2e-3 | Fig. legend | $z = -2.61$
| Sup. 9f | Wilcoxon Rank-sum Test | Online Methods Statistics | 1064, 911 Number of cells with at least five motifs in RW and VR, respectively | Fig. 5e legend | Mean +/- SEM | Fig. legend | 1.1e-12 | Fig. legend | $z = -7.11$
| Sup. 9g | t-test for correlation coefficient | Online Methods Statistics | 109 Number of cells recorded in both RW and VR on the same day with firing rate > 0.2 Hz in both RW and VR | Sup. Fig. 5a legend | Correlation coefficient | Fig. legend | 1.2e-3 | Fig. legend | $r = 0.31$
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<td>Number of cells with mean rate above 0.5Hz in the linearized ratemaps in VR random-pillar and VR systematic-pillar respectively</td>
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### Representative figures

1. Are any representative images shown (including Western blots and immunohistochemistry/staining) in the paper?
   If so, what figure(s)?
   
   Figure 1a, b,c,d  
   Figure 2c  
   Figure 3a,c,d  
   Figure 4a  
   Figure 5a,b,c,d  
   Figure 6a  
   Supplementary Figure 1  
   Supplementary Figure 4a,b  
   Supplementary Figure 6a  
   Supplementary Figure 7  
   Supplementary Figure 8a

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 #)?
   
   All the representative images are accompanied by the total number of recordings, corresponding quantifications, and significance levels. In the figure legends.

### 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.
   
   A large sample size was used to ensure statistical reliability, as reported in various places in the manuscript and the above table. The sample size is similar to the sample sizes employed in the field.
   
   Online Methods, Statistics.

2. Are statistical tests justified as appropriate for every figure?
   Where (section, paragraph #)?
   
   a. If there is a section summarizing the statistical methods in the methods, is the statistical test for each experiment clearly defined?
   
   Online Methods, Statistics.
   
   b. Do the data meet the assumptions of the specific statistical test you chose (e.g. normality for a parametric test)?
   Where is this described (section, paragraph #)?
   
   Non-parametric tests used.
   
   Online Methods, Statistics.
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 #)?

- SEM. Online Methods, Statistics.
- Given large sample sizes, large effect sizes, and use of non-parametric tests, this is not a concern.

d. Are tests specified as one- or two-sided? Two-sided. Online Methods, Statistics.

e. Are there adjustments for multiple comparisons? N/A

3. Are criteria for excluding data points reported? Yes, only cells with firing rate >0.2 Hz in both RW and VR were used for analysis in the two-dimensional environments. In the linearized one-dimensional rate maps the threshold was 0.5 Hz as commonly done. Rate thresholding is a standard practice to ensure cells have enough data to compute spatial tuning properties.

The order of running on RW and VR on the same days (if data was collected from both sessions) was randomized.

- Online Methods, Random Foraging in RW and VR.

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 #)?

- Yes, only cells with firing rate >0.2 Hz in both RW and VR were used for analysis in the two-dimensional environments. In the linearized one-dimensional rate maps the threshold was 0.5 Hz as commonly done. Rate thresholding is a standard practice to ensure cells have enough data to compute spatial tuning properties.

- Online Methods, Random Foraging in RW and VR.

5. Is a statement of the extent to which investigator knew the group allocation during the experiment and in assessing outcome included? Data collection and analysis were not performed blind to the conditions of the experiments.

- Online Methods, Statistics.

6. For experiments in live vertebrates, is a statement of compliance with ethical guidelines/regulations included? Yes.

- Online Methods, Subjects

7. Is the species of the animals used reported? Yes.

- Online Methods, Subjects

8. Is the strain of the animals (including background strains of KO/transgenic animals used) reported? N/A

- Online Methods, Subjects

9. Is the sex of the animals/subjects used reported? Yes.

- Online Methods, Subjects

10. Is the age of the animals/subjects reported? Yes.

- Online Methods, Subjects

11. For animals housed in a vivarium, is the light/dark cycle reported? Yes.

- Online Methods, Subjects
12. For animals housed in a vivarium, is the housing group (i.e. number of animals per cage) reported?
   Where (section, paragraph #)?
   Yes
   Online Methods, Subjects

13. For behavioral experiments, is the time of day reported (e.g. light or dark cycle)?
   Where (section, paragraph #)?
   Yes
   Online Methods, Subjects

14. Is the previous history of the animals/subjects (e.g. prior drug administration, surgery, behavioral testing) reported?
   Where (section, paragraph #)?
   Yes
   Online Methods, Surgery, Electrophysiology and Spike Sorting

   a. If multiple behavioral tests were conducted in the same group of animals, is this reported?
      Where (section, paragraph #)?
      Yes
      Online Methods, Methods Summary.

15. If any animals/subjects were excluded from analysis, is this reported?
   Where (section, paragraph #)?
   No animals were excluded.

   a. How were the criteria for exclusion defined?
      Where is this described (section, paragraph #)?
      N/A

   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 #)?
      N/A

**Reagents**

1. Have antibodies been validated for use in the system under study (assay and species)?
   N/A

   a. Is antibody catalog number given?
      Where does this appear (section, paragraph #)?
      N/A

   b. Where were the validation data reported (citation, supplementary information, Antibodypedia)?
      Where does this appear (section, paragraph #)?
      N/A

2. If cell lines were used to reflect the properties of a particular tissue or disease state, is their source identified?
   Where (section, paragraph #)?
   N/A
a. Were they recently authenticated?
   Where is this information reported (section, paragraph #)?
   N/A

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.

1. Are accession codes for deposit dates provided?
   Where (section, paragraph #)?
   N/A

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.
   Custom software and algorithms were developed specifically for each analysis reported here and were written in MATLAB.

2. Is computer source code/software provided with the paper or deposited in a public repository? Indicate in what form this is provided or how it can be obtained.
   Email corresponding author

Human subjects

1. Which IRB approved the protocol?
   Where is this stated (section, paragraph #)?
   N/A

2. Is demographic information on all subjects provided?
   Where (section, paragraph #)?
   N/A

3. Is the number of human subjects, their age and sex clearly defined?
   Where (section, paragraph #)?
   N/A

4. Are the inclusion and exclusion criteria (if any) clearly specified?
   Where (section, paragraph #)?
   N/A
5. How well were the groups matched?
   Where is this information described (section, paragraph #)?
   [N/A]

6. Is a statement included confirming that informed consent was obtained from all subjects?
   Where (section, paragraph #)?
   [N/A]

7. For publication of patient photos, is a statement included confirming that consent to publish was obtained?
   Where (section, paragraph #)?
   [N/A]

› 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?
   [N/A]

   a. If yes, is the number rejected and reasons for rejection described?
      Where (section, paragraph #)?
      [N/A]

2. Is the number of blocks, trials or experimental units per session and/or subjects specified?
   Where (section, paragraph #)?
   [N/A]

3. Is the length of each trial and interval between trials specified?
   [N/A]

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.
   [N/A]

5. Is the task design clearly described?
   Where (section, paragraph #)?
   [N/A]

6. How was behavioral performance measured?
   [N/A]

7. Is an ANOVA or factorial design being used?
   [N/A]

8. For data acquisition, is a whole brain scan used?
   If not, state area of acquisition.

   a. How was this region determined?
   [N/A]
9. Is the field strength (in Tesla) of the MRI system stated?
   a. Is the pulse sequence type (gradient/spin echo, EPI/spiral) stated?
      N/A
   b. Are the field-of-view, matrix size, slice thickness, and TE/TR/flip angle clearly stated?
      N/A

10. Are the software and specific parameters (model/functions, smoothing kernel size if applicable, etc.) used for data processing and pre-processing clearly stated?
    N/A

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 #)?
    N/A

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 #)?
    N/A

13. How were anatomical locations determined, e.g., via an automated labeling algorithm (AAL), standardized coordinate database (Talairach daemon), probabilistic atlases, etc.?
    N/A

14. Were any additional regressors (behavioral covariates, motion etc) used?
    N/A

15. Is the contrast construction clearly defined?
    N/A

16. Is a mixed/random effects or fixed inference used?
   a. If fixed effects inference used, is this justified?
      N/A

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?
      N/A

18. If the threshold used for inference and visualization in figures varies, is this clearly stated?
    N/A

19. Are statistical inferences corrected for multiple comparisons?
   a. If not, is this labeled as uncorrected?
      N/A
20. Are the results based on an ROI (region of interest) analysis?
   a. If so, is the rationale clearly described? N/A
   b. How were the ROI’s defined (functional vs anatomical localization)? N/A

21. Is there correction for multiple comparisons within each voxel? N/A

22. For cluster-wise significance, is the cluster-defining threshold and the corrected significance level defined? N/A

### Additional comments

Additional Comments

To maintain readability, degrees of freedom and many test statistics were not reported but are available in the supplementary methods checklist.