6 Appendix

6.1 Neural responses

Supplementary Figure S3 presents a unique visualization of DF/F traces corresponding to different neurons. The plot provides a glimpse into the temporal dynamics of neuronal responses offering a detailed perspective of how these signals evolve over time, pre- and post- stimulus presentation, compared to the peak DF/F values. The variance observed in the profiles and magnitude of these DF/F traces indicates the diversity of neuronal response patterns based on factors such as brain region, genotype, and functional characteristics.

Furthermore, **Supplementary Figure S4** shows an overlay of DF/F traces from the VISal brain region alongside 1D feature representation signals from NeuRN and non-NeuRN models. It highlights the close alignment of NeuRN-based traces with the biological DF/F traces, demonstrating NeuRN's capability to effectively capture neural patterns in this brain region. The x-axis represents time in seconds, while the y-axis corresponds to neural amplitude. In contrast, the **Supplementary Figure S5** presents an overlay of DF/F traces from the VISpm brain region with the same feature representation signals. This figure illustrates a case where NeuRN models struggle to fully replicate the neural dynamics of the region, as reflected in the less precise alignment compared to VISal. These observations underscore NeuRN's strengths in certain brain regions while pointing to potential challenges in regions with complex neural dynamics.

6.2 DNN training details

We used DNN models pre-trained on ImageNet, a large-scale and diverse image dataset widely used in deep learning. ImageNet pre-training enables the model to develop a broad set of feature detectors that can be applied across various visual tasks. We fine-tuned the models on a specifically curated subset of the CIFAR-100 dataset as described. We applied these models to the MNIST datasets for domain generalization tasks. Throughout the training phase, early stopping was consistently applied to prevent over-fitting and to optimize performance. In order to train the DNN models, a learning rate of 0.001, batch size of 256 and Adam optimizer was used. Early stopping patience of 5 was used with validation accuracy as a performance metric. All experiments were performed using NVIDIA TITAN RTX GPU.

6.3 Genotype abbreviations

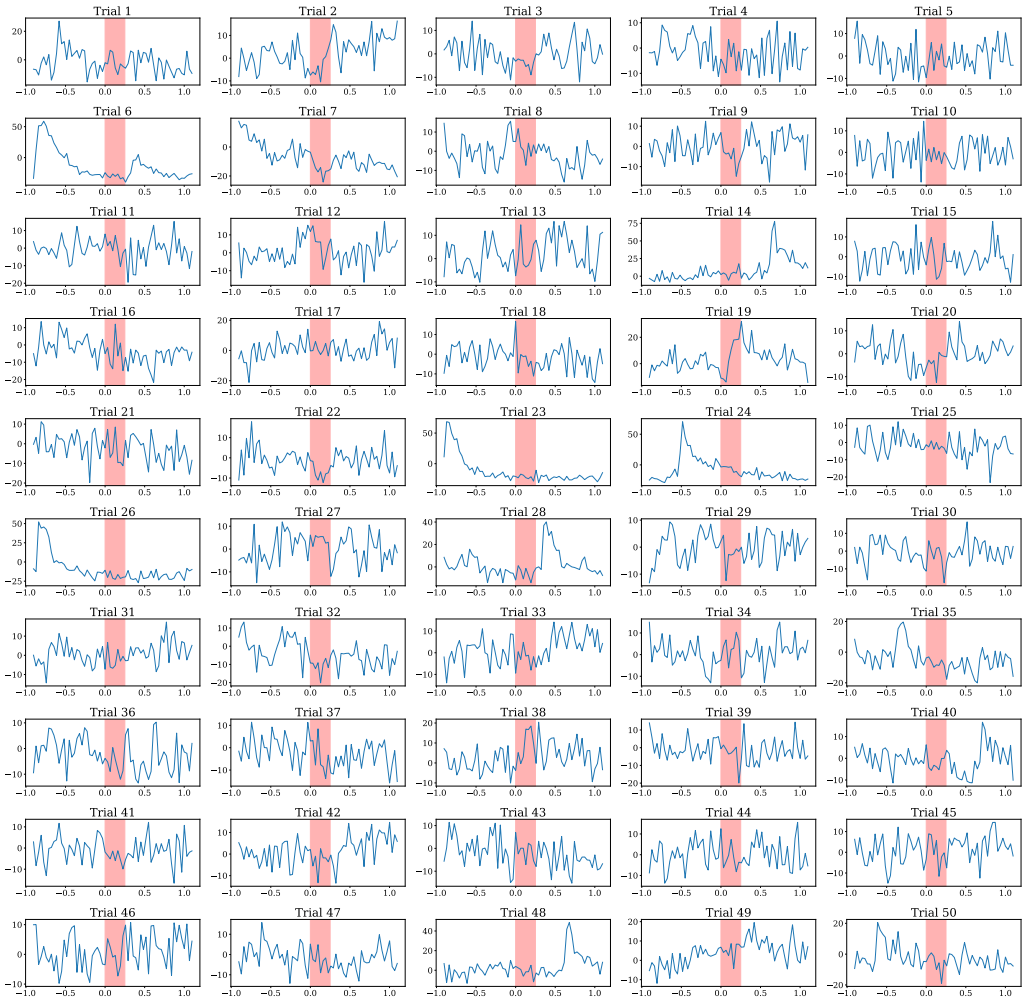
The genotype abbreviations used in Figure 2 represent different transgenic mouse lines used in this study. The complete genotype specifications for all 22 mouse lines, are provided in **Supplementary Table S1**.

Supplementary Figure S1: A comprehensive overview of the Natural Scenes Dataset, which comprises a diverse array of real-world images. Each image presents a unique scene, contributing to the dataset's broad scope that spans across various landscapes, urban areas, and natural phenomena.

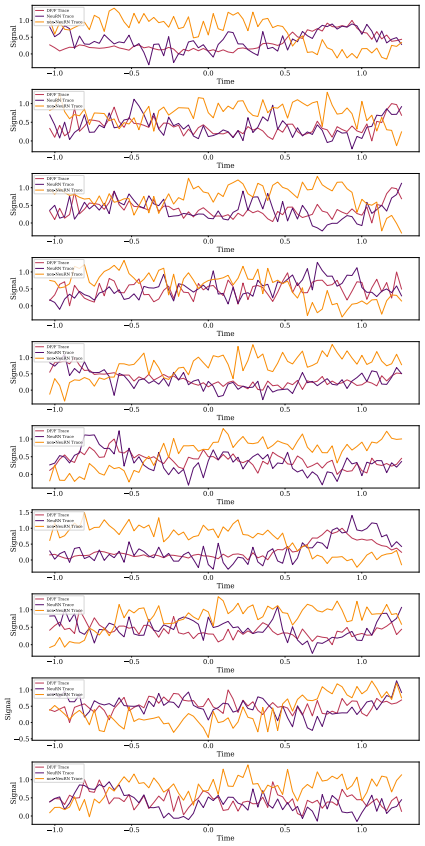
Supplementary Figure S2: A curated subset of the CIFAR-100 dataset, specifically focusing on natural scenes. These images cover a wide spectrum of natural environments, providing a compact yet varied dataset for studying natural image perception and related neural dynamics.

Abbreviation	**Full Name**
Cux2_1	Cux2-CreERT2/wt;Camk2a-tTA/wt;Ai93(TITL-GCaMP6f)/wt
Rbp4_1	Rbp4-Cre_KL100/wt;Camk2a-tTA/wt;Ai93(TITL-GCaMP6f)/Ai93(TITL-GCaMP6f)
Cux2_2	Cux2-CreERT2/wt;Camk2a-tTA/wt;Ai93(TITL-GCaMP6f)/Ai93(TITL-GCaMP6f)
Slc17a7_1	Slc17a7-IRES2-Cre/wt;Camk2a-tTA/wt;Ai93(TITL-GCaMP6f)/wt
Cux2_3	Cux2-CreERT2/Cux2-CreERT2;Camk2a-tTA/wt;Ai93(TITL-GCaMP6f)/Ai93(TITL-GCaMP6f)
Emx1_1	Emx1-IRES-Cre/wt;Camk2a-tTA/wt;Ai93(TITL-GCaMP6f)/wt
Rorb_1	Rorb-IRES2-Cre/wt;Camk2a-tTA/wt;Ai93(TITL-GCaMP6f)/Ai93(TITL-GCaMP6f)
Fezf2	Fezf2-CreER/wt;Ai148(TIT2L-GC6f-ICL-tTA2)/wt
Scnn1a_1	Scnn1a-Tg3-Cre/wt;Camk2a-tTA/wt;Ai93(TITL-GCaMP6f)/wt
Ntsr1	Ntsr1-Cre_GN220/wt;Ai148(TIT2L-GC6f-ICL-tTA2)/wt
Rbp4_2	Rbp4-Cre_KL100/wt;Camk2a-tTA/wt;Ai93(TITL-GCaMP6f)/wt
Emx1_2	Emx1-IRES-Cre/wt;Camk2a-tTA/wt;Ai93(TITL-GCaMP6f)/Ai93(TITL-GCaMP6f)
Nr5a1_1	Nr5a1-Cre/wt;Camk2a-tTA/wt;Ai93(TITL-GCaMP6f)/Ai93(TITL-GCaMP6f)
Nr5a1_2	Nr5a1-Cre/wt;Camk2a-tTA/wt;Ai93(TITL-GCaMP6f)/wt
Rorb_2	Rorb-IRES2-Cre/wt;Camk2a-tTA/wt;Ai93(TITL-GCaMP6f)/wt
Tlx3	Tlx3-Cre_PL56/wt;Ai148(TIT2L-GC6f-ICL-tTA2)/wt
Slc17a7_2	Slc17a7-IRES2-Cre/wt;Camk2a-tTA/wt;Ai94(TITL-GCaMP6s)/wt
Emx1_3	Emx1-IRES-Cre/wt;Camk2a-tTA/wt;Ai93(TITL-GCaMP6f)-hyg/wt
Scnn1a_2	Scnn1a-Tg3-Cre/wt;Camk2a-tTA/wt;Ai93(TITL-GCaMP6f)/Ai93(TITL-GCaMP6f)
Vip	Vip-IRES-Cre/wt;Ai148(TIT2L-GC6f-ICL-tTA2)/wt
Pvalb	Pvalb-IRES-Cre/wt;Ai162(TIT2L-GC6s-ICL-tTA2)/wt
Sst	Sst-IRES-Cre/wt;Ai148(TIT2L-GC6f-ICL-tTA2)/wt

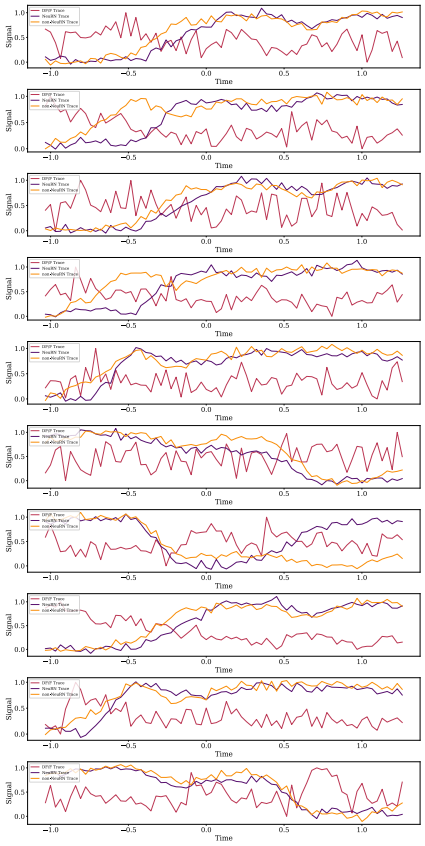
Supplementary Table S1: Mapping of genotype abbreviations to full names with Cre-labelling techniques used in **Figure 2**.



Supplementary Figure S3: A variety of DF/F traces representing activation of different neurons for various trials, providing insights into their unique signature of activity profile. Here x-axis is time in seconds and y-axis is neural amplitude.



Supplementary Figure S4: Overlay of DF/F traces from brain region VISal and 1D feature representation signals of NeuRN and non-NeuRN models, highlighting the close alignment of NeuRN traces with DF/F traces in certain brain regions. Here x-axis is time in seconds and y-axis is neural amplitude.



Supplementary Figure S5: Overlay of DF/F traces from brain region VISpm and 1D feature representation signals of NeuRN and non-NeuRN models, illustrating a case where NeuRN models struggle to accurately capture the neural dynamics. Here x-axis is time in seconds and y-axis is neural amplitude.