Cortical bases of temporal asymmetries in auditory perception

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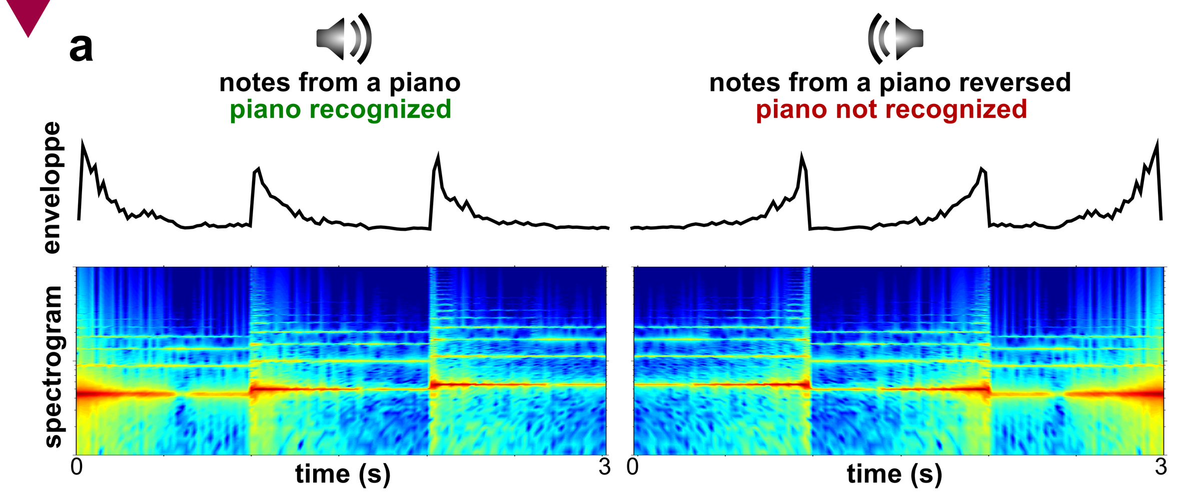
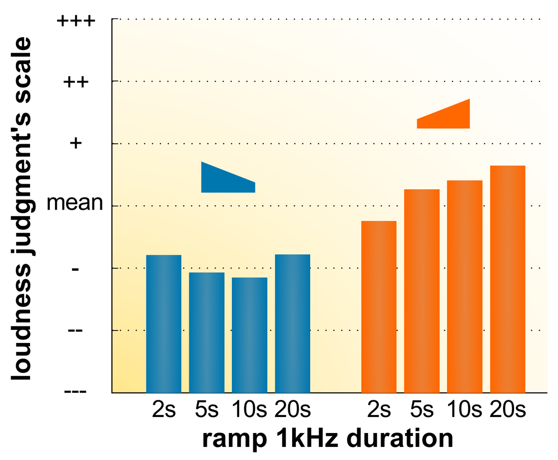
Introduction



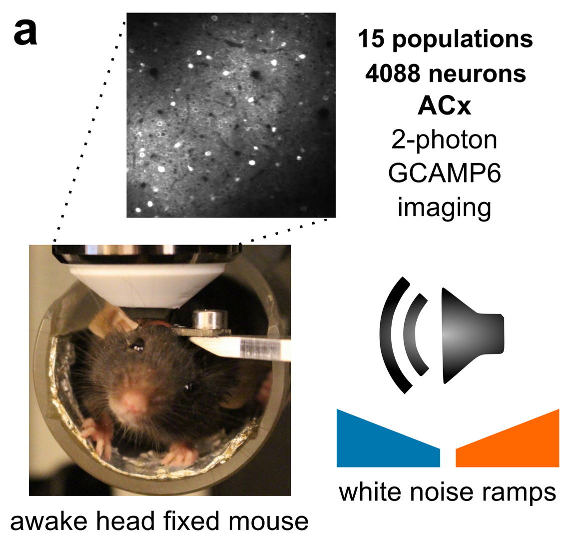


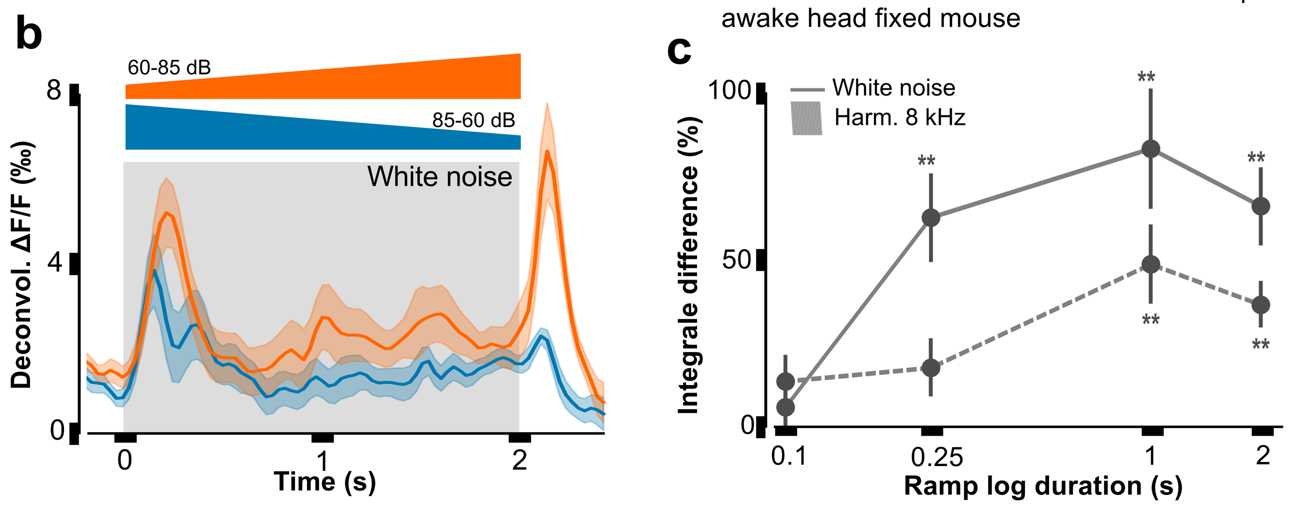
Natural sounds display strong temporal variations of intensity, which are crucial features for auditory perception and recognition (**a**). Strikingly, for example, humans perceive a tone that increases in intensity as louder than the same tone with a decreasing intensity profile, although both sounds have the same energy and frequency content (**b**).

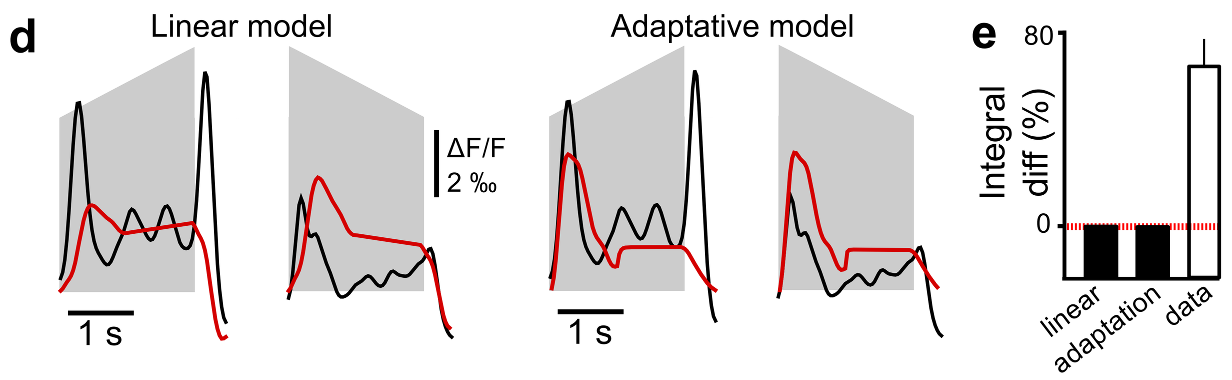
The underlying neuronal mechanisms of perceptual asymmetries for intensity-modulated sounds are still elusive

Two-photon recordings

We have measured the activity in 15 populations of neurons in the auditory cortex of five awake mice using GCAMP6 two-photon calcium imaging, yielding a total of 4088 neurons (**a**). We observed that the time integral of cortical population firing rate is much larger for sounds ramping-up than for sounds ramping-down (**b**,**c**).
This asymmetry is not capture by linear models or adaptative models (**d**,**e**)



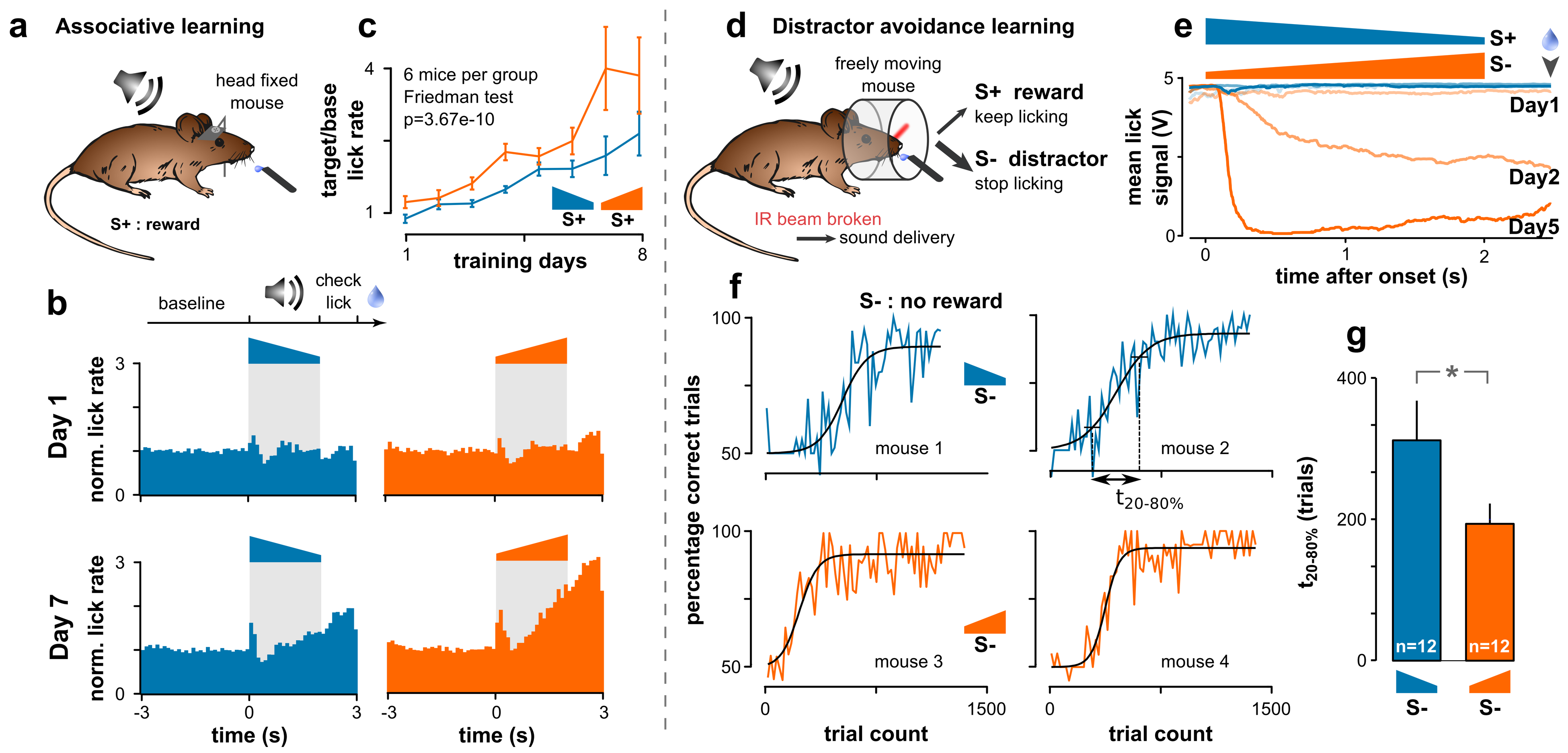




ACx response to up- and down-ramps are asymmetric demonstrating strong non-linearities

Behavioral experiments

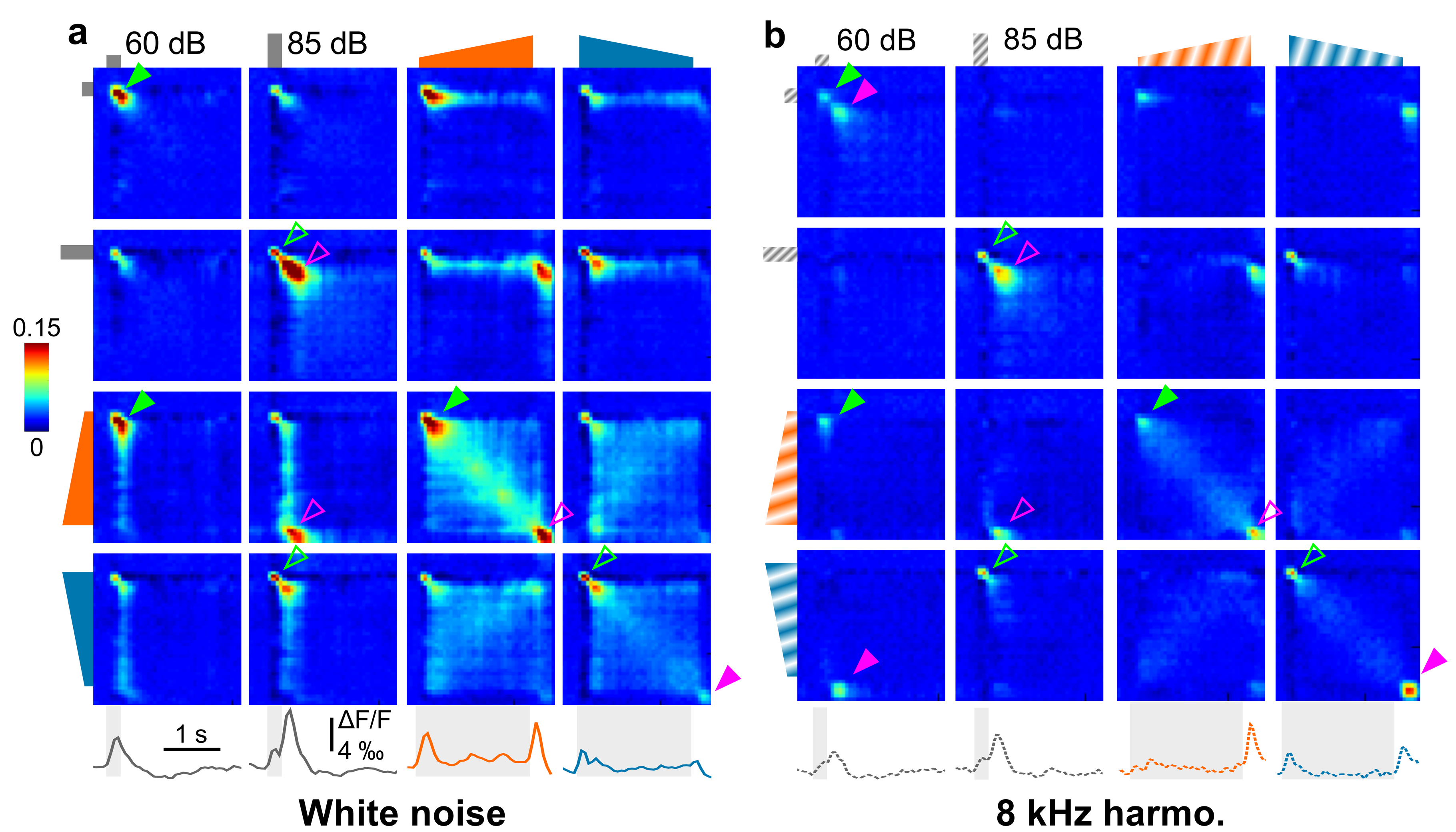
We used behavioral experiments to measure the saliency of a sound reflected by associative learning speed (**a**) : Up-ramps were more rapidly associated to the licking than downramps (**b**,**c**).
We next used a Go/NoGo discrimination task with a rewarded sound (**S+**) and a non rewarded sound (**S-**). (**d**) Using a previously published model we predicted that the learning phase should be shorter if the S- sound is more salient. We observed that mice learn faster to avoid licking when S- is the up-ramp than when it was the down-ramp (**e**,**f**,**g**).



The asymmetry of cortical population responses reflects an asymmetry in perceived saliency

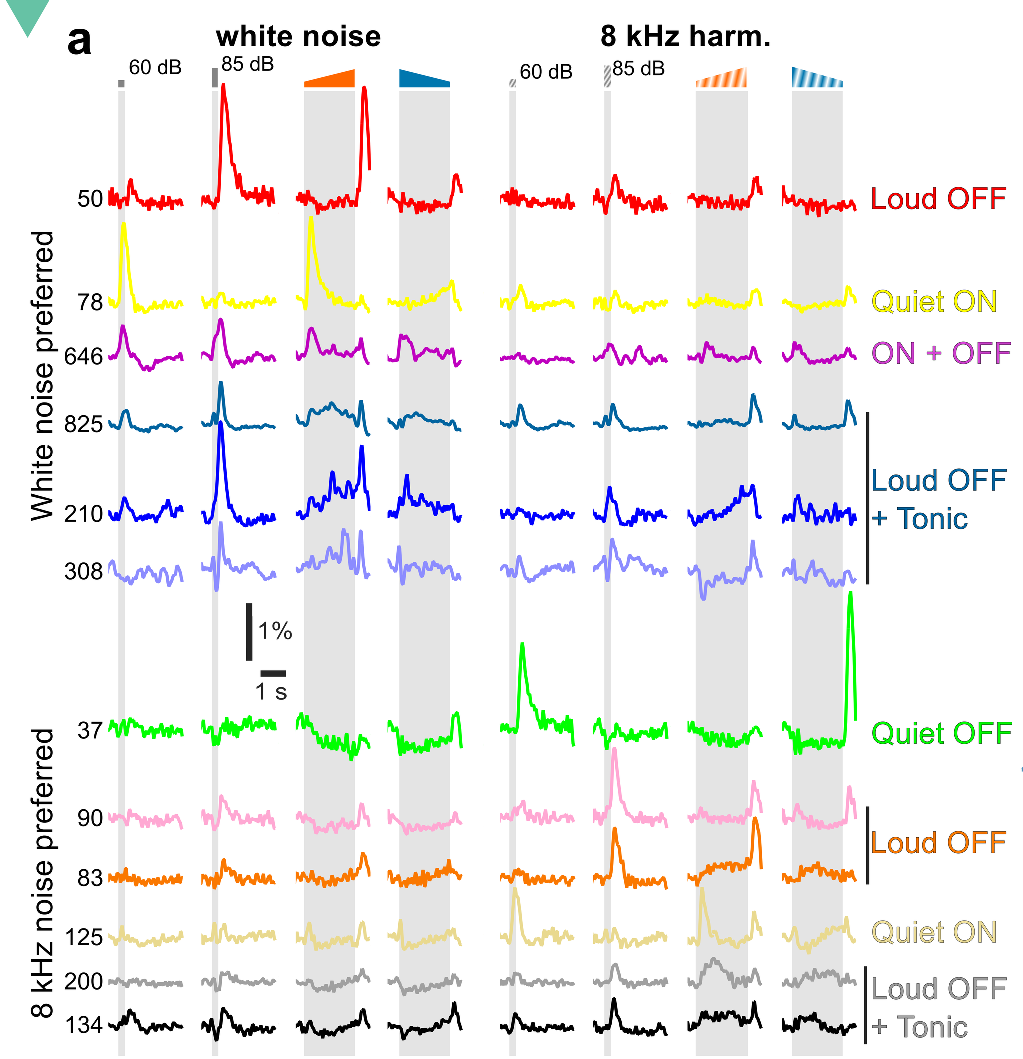
Population analysis

Correlations analysis showed that specific acoustic features produce distinct population patterns. Interestingly, similar temporal features were encoded for white noise (**a**) and harmonic sounds (**b**):

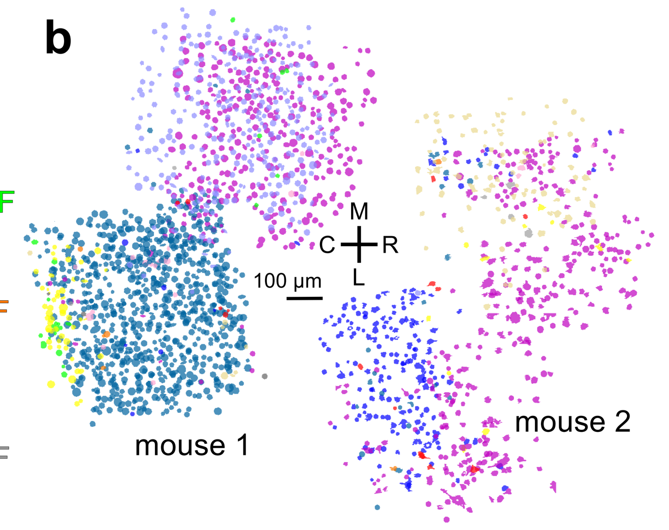


Asymmetric sequences of population patterns occur during up- and down-ramps

Functional recordings



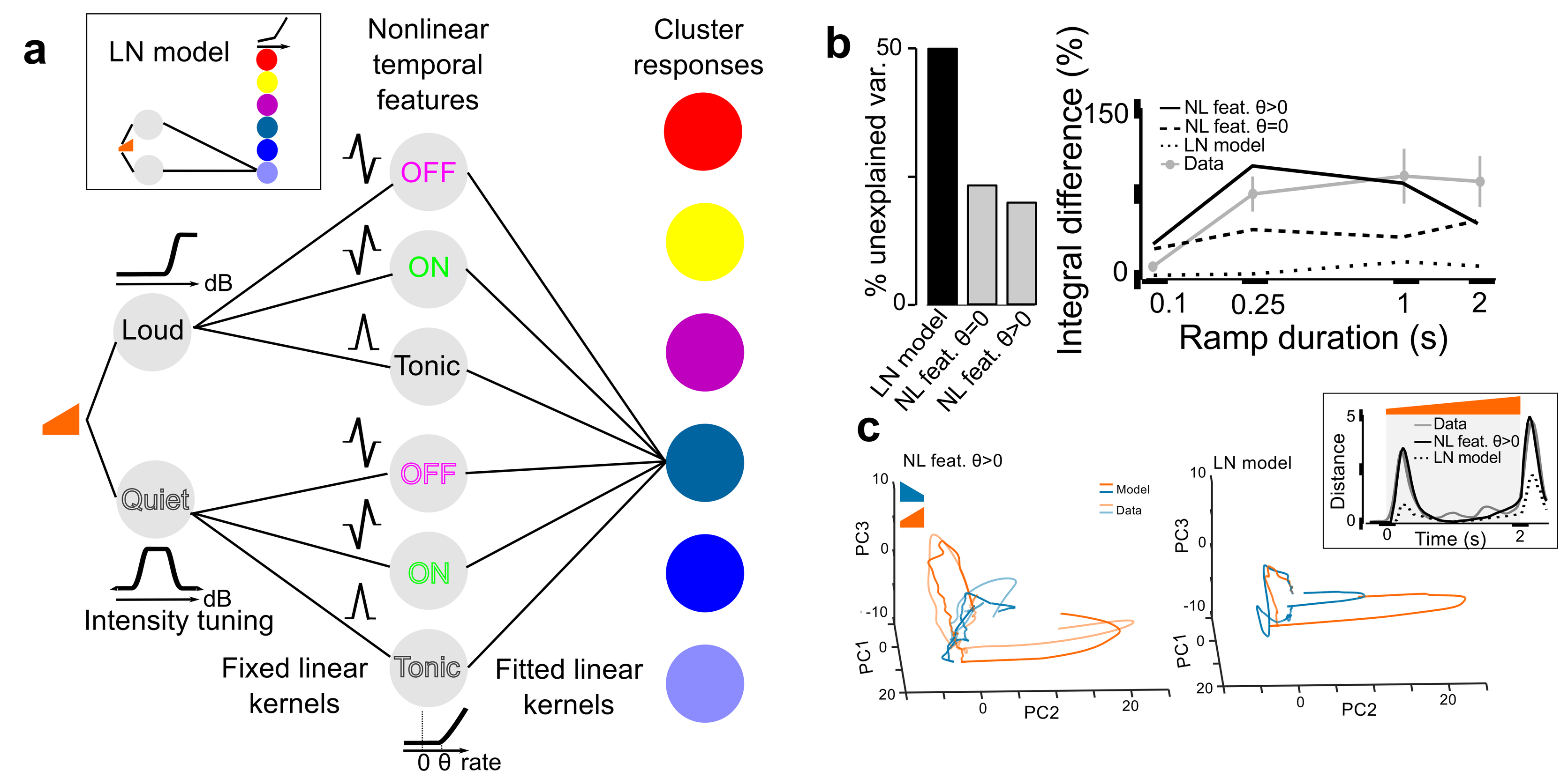
Non-supervised hierarchical clustering highlighted different neuronal assemblies with specific response types (**a**). Clusters show preference for white noise or harm 8 kHz sounds and act as acoustic feature detectors (ON, OFF and loud, quiet combinaisons). Some clusters responded to unitary features. Others respond to a mixture of features. Interestingly, functional assemblies also cluster in space (**b**).



Functional neuronal assemblies clustered in space encode complex sound features combining intensity and temporal information

Data-driven model

Linear and classic linear-nonlinear (LN) models (**a top left**) fail to reproduce the cortical asymmetry observed (**b**,**c**). We construct a multilayer non-linear model (**a**) which reproduces the asymmetry between up- and down-ramps (**b**,**c**).



A multilayer model is required to reproduce the cortical asymmetry

Conclusion

Beyond proposing a mechanism for perceptual asymmetry that may emphasize approaching sound sources, our results suggest that ACx assemblies produce complex responses that cannot be modeled by classic LN models. A series of linear and nonlinear filters is needed to reproduce such complex behavior and to reproduce the asymmetry.