the identity of the phrase two steps previously in the sequence's history (a 'second-order' correlation). Most of the correlations between ROI activity and phrase sequence depended on the identities of preceding (rather than future) phrases, and these 'past' correlations were stronger than correlations depending on the identity of future phrases. Thus, the activity of some HVC neurons reflects the sequence of preceding phrases.

Next, the authors investigated whether this subset of HVC neurons showed properties that are predicted of a neural basis of long-range syntax. To be able to support long-range syntax, neurons would need to be able to maintain information about actions in a sequence over the course of multiple actions. Indeed, the authors found that some sequence-correlated ROIs carried forward information about the identity of the first of a sequence of four phrases. This was the case even when the final phrase of the sequence was replaced with singing cessation, confirming that the information these neurons carried corresponded to the first phrase itself, rather than future phrase choice. These results suggest that some HVC PNs are able to mediate long-range syntax rules in birdsong.

Neurons that mediate long-range syntax are also expected to provide context-specific information particularly around the time of the complex transition. In line with this, more sequence-correlated ROIs were observed immediately before or after complex transitions, when information about past context would be most needed. Moreover, the authors found examples in which the activity of multiple ROIs was much more predictive of future and past phrase identity than was the activity of any individual ROI, suggesting that long-range syntax is supported by the synergy of the activity of a network of neurons.

Together, this study provides evidence that a subset of HVC PNs maintain information about phrase sequences required to implement long-range syntax rules for complex transitions in birdsong.

Natasha Bray

ORIGINAL ARTICLE Cohen, Y. et al. Hidden neural states underlie canary song syntax. *Nature* **582**, 539–544 (2020)

activated are associated with certain histone methylation 'marks'. In postnatal *Sst* and *Vip* neurons, methylation marks for the primed state and active state were acquired at the same time, suggesting these enhancers are activated de novo.

The authors then asked what triggered activation of these enhancers and reasoned that, as postnatal development is regulated by neuronal activity, activity-regulated TFs such as those in the AP1 family might play a part. Indeed, levels of AP1 family TFs (such as FOS) increase substantially as *Sst* and *Vip* neurons mature. Many enhancer sequences that were selectively activated postnatally in a subtype-specific manner were enriched for AP1 binding sites and bound FOS. In *Sst* neurons, postnatally activated enhancers whose AP1 binding sites are mutated due to genetic variation did not become activated, indicating that AP1 family TFs are required for enhancer activation.

The authors then focused their attention on a cluster of postnatally activated enhancers upstream of the *Igf1* gene, which encodes a secreted factor that mediates activity-dependent inhibition of *Vip* neurons in visual cortex. This enhancer cluster contains AP1 binding sites and interacts with the *Igf1* promoter and becomes activated as *Vip* neurons mature. In addition, visual stimulation of dark-reared mice led to higher *Igf1* enhancer activation compared with unstimulated controls.

Finally, the authors overexpressed the inward rectifying potassium channel KIR2.1 in *Sst* neurons to reduce their activity. Overexpressing KIR2.1 resulted in lower expression of activity-regulated genes compared with controls overexpressing a mutated form of KIR2.1.

Together, these findings suggest that during early postnatal maturation of the brain, activity-induced AP1 family TFs contribute to the activation of enhancers that drive subtype-specific, activity-dependent gene transcription.

Sian Lewis

ORIGINAL ARTICLE Stroud, H. et al. An activity-mediated transition in transcription in early postnatal neurons. *Neuron* https://doi.org/10.1016/j.neuron.2020.06.008 (2020)

IN BRIEF

TECHNIQUES

Soma trapping sharpens signals

Imaging fluorescent proteins is a common method to assess the organization and function of neural circuits. However, overlapping fluorescence from nearby axons and dendrites can make it difficult to pick out signals arising from individual neurons. Here, Chen et al. and Shemesh et al. show that confining fluorescent proteins to the cell body can limit such cross-contamination. To improve the resolution of neuronal calcium imaging, Shemesh et al. screened a series of proteins composed of GCaMP calcium indicators fused to various peptides and identified two 'somatic GCaMPs' with expression that was restricted to the cell body. Taking a similar approach, Chen et al. tethered a GCaMP indicator directly to the ribosome, a macromolecule found within the cell body. In both studies, there was a reduction in the contaminating fluorescent signal from the neuropil, allowing for a better visualization of the somatic signal. The authors demonstrated the advantages of this approach for the assessment of calcium dynamics in cultures, slices and in vivo experiments. Chen et al. further showed that tethering a GFP-binding nanobody to the ribosome can also boost somatic fluorescence in GFP reporter mice, providing additional support for the use of somatic targeting in cellular imaging.

ORIGINAL ARTICLES Chen, Y. et al. Soma-targeted imaging of neural circuits by ribosome tethering. *Neuron* https://doi.org/10.1016/j.neuron.2020.05.005 (2020) | Shemesh, O. A. et al. Precision calcium imaging of dense neural populations via a cell-body-targeted calcium indicator. *Neuron* https://doi.org/10.1016/j.neuron.2020.05.029 (2020)

GUT–BRAIN AXIS

Bacteria bias behaviour

Bacteria have been shown to produce chemical signals that can alter neural activity and behaviour; however, the mechanisms involved are unclear. Here, the authors show that the ingestion of the gut-colonizing bacterial species *Providencia* by *Caenorhabditis elegans* reduces worms' aversive responses to the usually repellent alcohol octanol and biases their feeding choices to make them more likely to select *Providencia*. The authors find that the bacteria exert this effect through the production of tyramine, which — following its conversion to octopamine — activates receptors on ASH sensory neurons to modulate the worms' aversive responses and food selection.

ORIGINAL ARTICLE O'Donnell, M. P. et al. A neurotransmitter produced by gut bacteria modulates host sensory behaviour. *Nature* https://doi.org/10.1038/s41586-020-2395-5 (2020)

SENSORY SYSTEMS

Probing olfactory patterns

Identifying the spatial and temporal features of neuronal population activity that drive perception is a key goal of sensory coding research. Here, the authors trained mice to discriminate between different 'synthetic odours' created by optogenetically activating olfactory bulb neurons in specific spatial and temporal patterns. Subsequent systematic variation of spatial or temporal aspects of the activation patterns allowed the authors to determine which features have the greatest influence on perception (assessed via task performance) and to generate a model that could replicate the behavioural responses to different activity patterns. The study reveals some key principles of olfactory coding and provides evidence for the importance of both the spatial and the temporal patterns of neuronal activation in perception.

ORIGINAL ARTICLE Chong, E. et al. Manipulating synthetic optogenetic odors reveals the coding logic of olfactory perception. *Science* **368**, eaba2357 (2020)