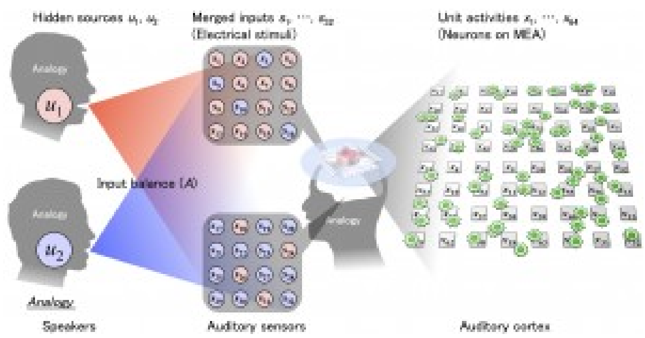
A cocktail party in a dish: How neurons filter the chatter

January 27 2016, by Emilie Reas



Distinct patterns of neural activation simulate the cocktail party effect of hearing multiple speakers. (Isomura et al., 2015)

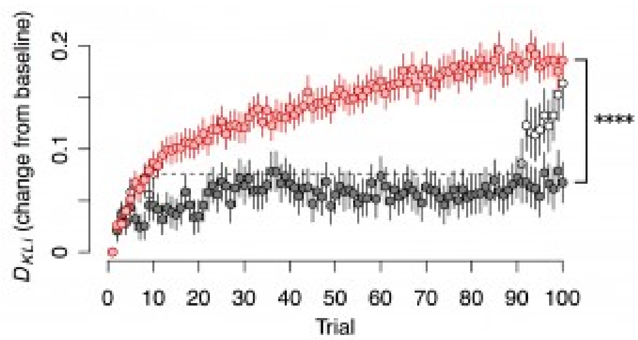
While dining with a friend at a noisy restaurant, you listen attentively to her entertaining account of last night's date. Despite the cacophony flooding your auditory system, your brain remarkably filters your friend's voice from the irrelevant conversations at neighboring tables. This "cocktail party effect," the ability to attend to select input amidst a distracting background, has fascinated researchers since its characterization in the 1950's. Although psychological and sensory models have offered insight into why human brains are so exquisitely equipped to perform this selective attention, researchers haven't yet pinned down how neurons process mixed information to respond to the important and suppress the irrelevant. In their new paper published in *PLOS Computational Biology*, researchers from the University of Tokyo revealed that individual neurons learn to "tune in" to one input while ignoring others, offering an intriguing explanation for how rapid neural plasticity may give rise to the cocktail party effect.

Sending neurons mixed messages

Based on many earlier studies showing that neural networks can learn by changing their activity based on experience, the authors wondered whether neurons could also be trained to distinguish among sensory experiences. To test this idea, they recorded electrical activity from cultured rat cortical neurons. They electrically stimulated the neurons according to two stimulation patterns, to provide two unique hidden sources of input, simulating the cocktail party effect of hearing a mixture of voices. In some conditions both input patterns were activated, while in others one, the other, or neither input pattern was activated. They repeated variations of these stimulations for 100 trials in many samples to track how the neural responses changed over exposure to the stimuli.

Learning to discriminate

Over the course of training, neurons altered their likelihood of spiking to the input patterns. Roughly half of the neurons increased their response to one source and reduced their response to the other, while the other half increased responsiveness to the other source. A discrimination index used to measure preference for one input over the other showed that this bias increased across all electrodes over the training period. Even neurons exposed to the stimuli only briefly – trained on only a fraction of the trials – still demonstrated a response preference up to a day later, suggesting that neural learning occurred rapidly and was long-lasting. Although first author Takuya Isomura speculates that "this could last several days," it's not permanent. "We have confirmed that training with another stimulation pattern could overwrite the neural preference to the past source. That is, even cultures that have learned a pattern set could learn another one."



Neurons increased their discrimination (DKLi) over the course of training when fully trained (red) and partially trained (white) but not when NMDA receptors were blocked (black). (Isomura et al., 2015)

But how, since biological systems can learn in various ways, did these cells so efficiently acquire and maintain this source bias? Blocking the cultures with an NMDA receptor antagonist largely prevented the neurons from developing an input preference, suggesting that learning occurred through NMDA receptor-dependent signaling, known to be important for long-term synaptic plasticity supporting memory formation. Furthermore, neurons only demonstrated discriminability if there was variance in the balance and frequency of the input patterns. This requirement for variance hinted that the neurons may follow independent components analysis (ICA)-like learning rules.

To better understand these learning dynamics, Isomura's group examined changes at the neuronal population level. A simple Hebbian learning model predicted that connectivity should increase both within and across neuron groups. Instead, synaptic connectivity increased between neuron groups with the same source preference, but decreased between neuron groups with different source preferences. A modified model of Hebbian learning (including state-dependent plasticity) better accounted for these observations, as it allowed for competition between neurons. As Isomura explains, "state-dependent Hebbian plasticity could facilitate the neural response to the source that effectively stimulates the nearest electrode, while it could depress that to the other source. In the future, using the connection strength estimation, we might be able to predict the neural preference before the stimulations."

As the neural networks changed, their internal and free energy decreased, whereas entropy increased. These energy changes did not occur with NMDA receptor blockade, suggesting that they are indeed attributable to learning-related synaptic plasticity. As connections strengthen between a neuronal group and its preferred source, the authors explain, mutual information increases between the neural system's inputs and outputs, lowering its overall free energy.

How does a discriminating neuron make a discriminating brain?

Although it's well established that neural activity changes with experience, Isomura and colleagues have shown for the first time that neurons can invoke these learning mechanisms to recognize and discriminate information. Neural networks accomplished this impressive feat by performing unsupervised learning – adhering to ICA and free-energy principles – to self-organize via activity-dependent plasticity.

So how might these findings help you stay engrossed in your friend's tale of first date mishaps, amidst distraction? There are obvious differences between an integrated brain, which can direct its attention at will to a sound it deems meaningful and important, and a neuronal culture, which (presumably) lacks this power of guided attention. However, in both cases, a brain or neuron must decorrelate a mishmash of inputs. Although speculative, the authors propose that attentional shifts towards important information can only occur if the brain can distinguish sensory input, beginning at the level of discrimination by individual neurons. Further research will help to explain how feedback between attentional and sensory systems orchestrates this elegant goal-directed sensory filtering. Despite the sense that "tuning in" to a friend's voice is automatic and effortless, studies have shown that this is a learned skill acquired early during life. Like other forms of learning, developing this ability likely relies on the plasticity of neurons adapting and responding to their experiences.

To Isomura, it's "a fascinating mystery why people can learn faster than machine learning that typically needs huge training. Interestingly, some learning properties (e.g., speed) of culture networks are more similar to machine learning rather than human behavior, while they consist of living cells. Thus, a series of this kind of studies might have a potential to fill the gap."

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