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Hundreds of single neurons recorded through the depth of human speech cortex

During awake brain surgery, a dense silicon probe recorded 685 neurons as patients heard sentences, showing which speech features single cells track and how tuning varies through cortex.

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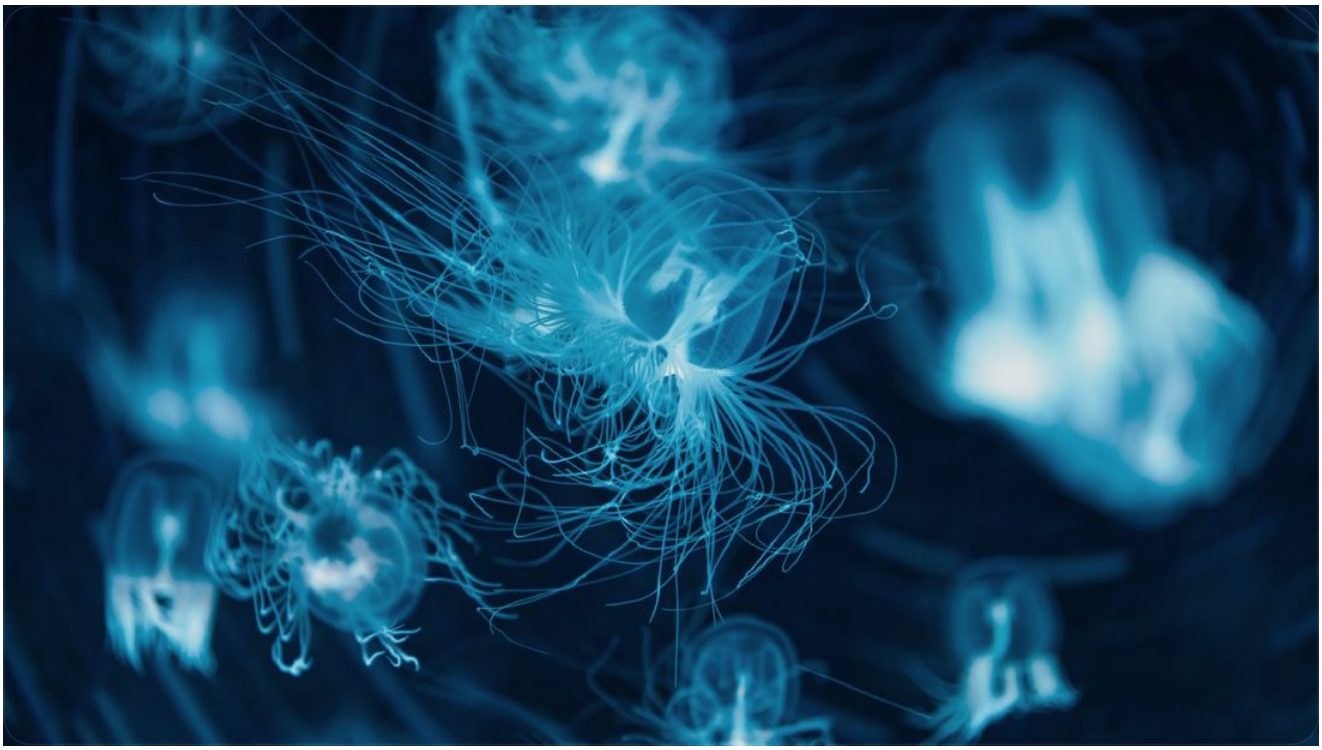


Photo: Ben Kim

In a 2023 study in Nature, researchers at the University of California, San Francisco, Columbia University and IMEC recorded 685 single neurons through the depth of the human superior temporal gyrus (STG), a ridge of cortex above the ear that is central to perceiving speech. In people, single neurons have usually been recorded only a few at a time. The authors report three main findings. Individual neurons respond to families of speech sounds. Every patch of cortex they sampled mixes several kinds of tuning. And the signal measured at the brain's surface draws on neurons at all depths.

Much of what is known about speech tuning in the STG comes from electrocorticography (ECoG). In ECoG, each electrode in a grid on the brain's surface sums the activity of thousands of neurons. Classic microelectrodes can isolate single cells but sample only a handful. Neither method shows how neurons are arranged across the cortical layers, the stacked sheets of cells running from the

surface to the white matter. In primary auditory cortex, neurons in a vertical column share narrow frequency tuning. The authors asked whether speech cortex is organised the same way, and which neurons produce the surface signal.

The team, led by Matthew Leonard and Edward Chang, worked with eight awake patients undergoing surgery for epilepsy or brain tumours. At nine sites they inserted a Neuropixels probe straight down into the STG. The probe is a thin silicon shank with 384 recording sites along 7.66 mm. Every insertion was in tissue removed later in the same operation. Patients listened to 110 sentences from 103 speakers, some repeated, for about eight minutes. The researchers then used spike sorting, which separates the recorded voltage into individual neurons' firing by the shape of each spike. It yielded 685 probable single neurons, 420 of them responsive to speech.

Individual neurons were not tuned to single phonemes, the basic sound units of a language. Instead they responded to groups of sounds produced in a similar way, such as plosives like p and t or fricatives like s and f. Other neurons responded to cues such as the start of a sentence. The authors fitted models built on 44 features. These included phonetic properties, relative pitch (pitch scaled to each speaker's own range), loudness and how predictable sounds and words were. The models predicted firing only modestly: the correlation between predicted and actual activity averaged 0.182 and reached 0.55 at best. Each site had a dominant feature type: pitch at four sites, phonetic features at four and sentence onsets at one. Even so, the dominant type accounted for only 25 to 62 per cent of the variance attributable to any single type. At three of the four pitch-dominated sites, pitch tuning was stronger near the surface and phonetic tuning stronger deeper down.

The neurons' frequency tuning was broad, unlike the narrow tuning of primary auditory cortex. On average a neuron responded across about four octaves, with several peaks and a bias towards low frequencies. Neurons favoured slow changes in the sound over time, averaging 1.64 cycles per second, rates relevant to intelligibility. Neurons roughly 3 to 4 mm deep responded fastest, in under 100 milliseconds. For most neurons, a neural-network model beat a simple linear one, suggesting that many respond to sound in context-dependent ways. The kind of context-dependence varied with depth.

Four participants had heard the same sentences earlier, during epilepsy monitoring with surface ECoG, and the paper compares that signal with spiking in two of them. The comparison centred on high gamma, the 70–150 hertz band widely used as a proxy for local firing. In one participant the averaged firing of 117 neurons closely tracked it, with correlations of 0.8 and 0.69 on two example sentences. Firing tracked the broadband local field potential, which mostly reflects currents at synapses, much less closely. Neurons at every depth correlated with high gamma, most strongly in the middle and deeper ranges. Earlier studies that used microelectrodes for both signals had instead found the strongest links with superficial neurons.

The limitations are substantial. Eight patients, all with epilepsy or tumours and only one recorded in the right hemisphere, make a small clinical sample, and every recording was in tissue slated for removal. Layer boundaries could not be identified directly, so depth claims are approximate. Surface and probe recordings were made at different times, with sites matched by surface vessels and folds. Depth patterns appeared at only some sites, and some correspondences were weak:

surface and neuronal tuning weights correlated at just 0.17. Listening was passive, sessions were brief and no non-speech sounds were played. The work is a detailed look at the single neurons beneath the surface signal, not a settled map of speech cortex.

PAPER	*Large-scale single-neuron speech sound encoding across the depth of human cortex*
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