envelopes would most likely become asymmetric, like gamma-tone filters. And if the filters were also assumed to be time-invariant, so that they are actually convolved with the input signal, then there would be no need for time-shifted filters. However, such modifications are unlikely to dramatically affect the time-frequency tiling scheme learned by the algorithm, which is really the main point of the paper.

Lewicki's results share an intriguing similarity to recent work in vision. Neurons in the visual cortex encode both the location and the spatial frequency of visual stimuli, and the trade-off between these two variables is analogous to that between timing and frequency in auditory coding. It has been shown that maximizing statistical independence or 'sparseness', of visual representations yields spatial receptive field properties similar to those of cortical neurons[10–12]. Curiously, the space–frequency tiling scheme of both the derived filters and those measured physiologically deviates from a wavelet in much the same way as Lewicki finds for the auditory system; bandwidth at high spatial frequencies is narrower than one would expect[13]. It is not yet clear whether this similarity is profound or simply coincidental.

Perhaps an even deeper question is why ICA accounts for neural response properties at the very earliest stage of analysis in the auditory system, whereas in the visual system ICA accounts for the response properties of cortical neurons, which are many synapses removed from photoreceptors. It seems likely that structural or neurobiological constraints are crucial in determining the stage of analysis appropriate for an independent component analysis of sensory signals. For example, the visual system is faced with an early bottleneck, where information from more than 100 million photoreceptors is funneled into 1 million optic nerve fibers. The representation is then expanded by a factor of 50 in the cortex. By contrast, in the auditory system, there is no early bottleneck, and the 3000 inner hair cells of the cochlea immediately fan out onto 30,000 auditory nerve fibers. Thus it seems that in both systems, ICA is applied at the point of expansion in the representation.

It is tempting to speculate about what additional insights may be gained regarding neural mechanisms higher up in the auditory stream—the midbrain, thalamus and cortex—by considering higher-order forms of structure over longer time scales and across multiple frequency bands. But this can not be done by simply applying the same analysis yet again. To add descriptive power, any additional stage of analysis would have to be nonlinear. Divisive normalization[9] or a signal power representation (as in a spectrogram) seem like obvious choices, and some preliminary work along these lines has produced promising results[14]. Conceivably, this type of approach could begin to account for more complex properties of auditory neurons such as multiple excitatory–inhibitory band structure or frequency modulation sensitivity[15], or perhaps even predict heretofore unnoticed response properties of cortical neurons. One gets the feeling that these findings are really just the tip of the iceberg, and that ahead lies a vast territory ripe for investigation.

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Color visions in the brain

Amy Center

A vivid perception of color is evoked by spoken words ("seven" is blue, for instance) in people with a condition called 'colored-hearing synesthesia'. This percept is associated with activity in an area of the brain that responds to color vision, report Julia Nunn and colleagues on page 371 of this issue. Because other visual areas are not activated, these results suggest that a conscious perception of color can be created by activation of the brain's 'color center' alone.

In a control experiment, normal subjects did not show activity in the color center in response to spoken words, even after they had been extensively trained to visualize particular colors in association with those words. The authors conclude that synesthesia is much more like a color hallucination than color imagery. Synesthesia may also have a genetic basis, as it runs in families and is strongly sex-linked (six times more common in women). The authors speculate that this condition may result from developmental errors in the formation or retraction of connections between auditory cortex and visual cortex.

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