speed of light in the medium to be reduced to just 17 metres per second.

Mücke and colleagues' study[1] now marries single-atom, strong-coupling cavity quantum electrodynamics with EIT. It brings low-loss, giant optical nonlinearities into the realm of both single photons and single atoms, and represents a milestone in the control of matter and light at the fundamental level. In their experiments, the authors trap one or a few rubidium atoms between two mirrors separated by half a millimetre, then monitor the transmission of a weak probe laser through the cavity — so weak, in fact, that on average the photon number inside the cavity is much less than one.

The key indicator for EIT is the contrast between transmission around the atomic resonance with and without application of the control laser field. The authors' observation[1] of a 20% contrast with just one atom provides a clear demonstration of entry into the above-mentioned realm, and readily achievable increases in the atom–cavity coupling strength should push the contrast well above 90%. This would enable operation of the single-atom system as a near-ideal transistor, controlling coherently the passage of light through the cavity. In fact, such increases would also make possible a Kerr-effect-induced 'photon blockade' mechanism, whereby excitation of the atom–cavity system by a single probe photon actually prevents further excitation by subsequent probe photons.

Besides its obvious relevance to conditional quantum dynamics and quantum-information processing, this mechanism is also central to recent fascinating proposals for strongly interacting photon gases and many-body phenomena (for example, quantum-phase transitions) in arrays of coupled cavities[7]. It would also enable EIT-based coherent transfer of quantum states between light and matter, in which a time-dependent control field leads to the 'mapping' of photons from an incident field onto cavity-confined atoms or vice versa[4], opening the door to a plethora of unique possibilities for quantum-state generation and manipulation. ■

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NEUROSCIENCE

fMRI under the spotlight

David A. Leopold

Analysis of a selected class of neuron in the brains of live animals using functional magnetic resonance imaging (fMRI) opens the door to mapping genetically specified neural circuits.

Advances in modern brain research are such that the line between science and science fiction can sometimes seem blurred. During the past 20 years, two advances have redefined the limits of experimental neuroscience. The first is functional magnetic resonance imaging (fMRI), which is widely used to map brain activity in humans. The second is genetic reprogramming of brain cells using molecular genetics. In an elegant study on page 788 of this issue, Lee *et al.*[1] combine these methods to demonstrate that, in the rat brain, the direct activation with light of a genetically defined subclass of neuron leads to robust fMRI responses. This finding not only demonstrates a tight link between neural firing and fMRI responses, but also introduces a powerful tool for mapping the function and dysfunction of large-scale brain circuits.

Functional MRI has had an enormous impact on modern science, with neuroscientists, psychologists, clinicians and even economists basing their conclusions on stunning images of brain activity obtained using this technique. But critics argue that, because fMRI measures changes in blood flow (haemodynamics) rather than information-carrying electrical signals within neurons, its results are often open to interpretation. Indeed, although it is tempting to explain positive fMRI signals as an increased rate of action-potential firing by neurons, this one-size-fits-all interpretation is unlikely to be correct. For instance, some electrophysiological experiments have shown that the simmering, sub-threshold activity of neurons is better correlated with haemodynamic fluctuations detected by fMRI than are action potentials[2]. Other evidence[3,4] suggests that the local coupling between action potentials and haemodynamic signals varies with behavioural context.

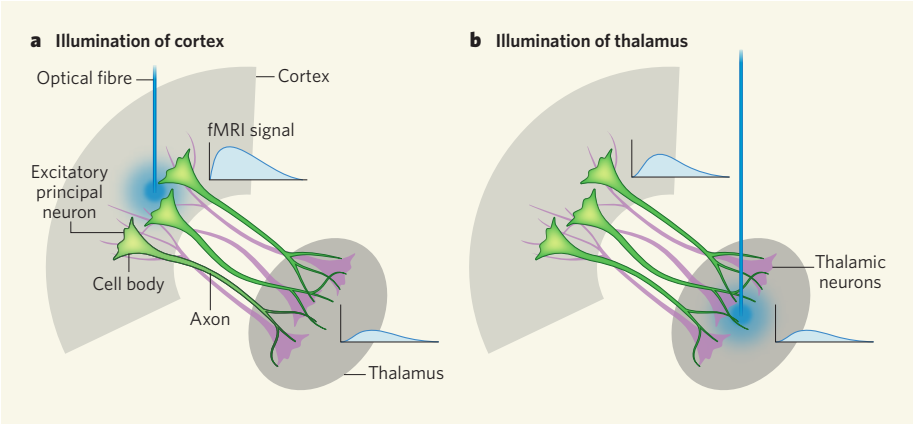

Figure 1 | fMRI responses to stimulations near and far. Lee *et al.*[1] genetically modified rat cortical neurons to produce light-sensitive membrane channels. They found that selective optical stimulation of cell bodies in the cortex (**a**) or axons in the thalamus (**b**) yield fMRI responses in both regions. The strongest and most immediate responses, however, were detected in the cortex in response to direct stimulation.

At the heart of the problem are the many complex cellular and molecular mechanisms that govern blood flow[5]. Lee *et al.*[1] therefore measured fMRI responses to the direct activation of a certain subtype of neuron, which they manipulated with optogenetics. For this, they used a viral vector to introduce two genes into rat brain cells called excitatory principal neurons. One of the genes encoded a fluorescent protein of glowing jellyfish origin[6], and so served as a marker to verify precisely which cells were manipulated. The other gene's product was channelrhodopsin, a light-sensitive, membrane-associated protein from a species of green alga[7]. By making a restricted class of cell sensitive to light in this way, the authors could selectively manipulate the activity of those cells while leaving other circuit elements unperturbed.

This group has previously used[8] such an approach to demonstrate moment-by-moment experimental control over a mouse's running behaviour — by illuminating neurons in an area of the motor cortex, the brain region responsible for voluntary movements. What makes the present study a technical tour de force is the researchers' measurement of haemodynamic and electrical responses to optogenetic stimulation in the brains of

anaesthetized rats inside an fMRI scanner.

In the vicinity of the optical fibre illuminating the rats' motor cortices, the authors found robust neural and fMRI responses within a conventional time course. This indicates that the direct activation of excitatory cortical neurons somehow triggers changes in local blood flow. Such stimulation of a well-defined subclass of neuron goes a step further than previous sensory stimulation and electrical microstimulation approaches, in which activation was less specific. What's more, Lee *et al.* predict that emerging tools will soon allow cells to be targeted on the basis of not only the genetic markers they express, but also their morphology and tissue topology[9]. If so, a further dissection of the cells that are particularly important for neurovascular coupling should be possible in the future.

While optically stimulating the motor cortex, Lee *et al.* also detected robust fMRI responses in the thalamus, a structure in the middle of the brain to which neurons of the motor cortex project axonal processes (Fig. 1a). Both the neural responses and fMRI responses in the thalamus were more sluggish than in the cortex, which the authors attribute to network delays; this point, however, requires further study.

Intriguingly, direct illumination of the thalamus also resulted in fMRI responses, despite the region's distance from the cell bodies of the manipulated motor-cortex neurons (Fig. 1b). These responses reflect the expression of light-sensitive channels in the cortical axons projecting into the thalamus. Remote optical stimulation of axons — which has previously been combined with electrophysiological recordings[10] to study long-range connections in brain slices — thus offers a new and powerful way to probe anatomical and functional connectivity using fMRI.

The finding that direct excitation of principal neurons leads to positive haemodynamic responses will be important for the research community interested in functional brain imaging, as it shows a causal link between the firing of a class of neuron and the fMRI signal. However, this observation should be interpreted with caution: it is likely that the downstream neural and non-neural elements also make a complex contribution to the vascular response (see Lee and colleagues' discussion[1]).

The main impact of this study[1] will be in providing alternative ways to map neural circuits. The combination of optogenetics and fMRI permits, for the first time, investigation of genetically specified, large-scale networks in the brains of live animals — for example, networks that may be disrupted in mental illness in humans. The method could also allow researchers to track the formation of neural circuits during development, as connections are steered and regulated by patterns of gene and protein expression. And when applied to experimental models of neurological and psychiatric disease, the approach may help to determine when and how certain regions of the brain fail to connect properly. Finally, the anticipated use of optogenetics as a tool for human deep-brain stimulation[9] can readily be combined with fMRI scanning, extending the methods introduced here to the mapping of activity in the human brain.

Specifically, this approach would allow researchers to visualize the responses to stimulation of well-defined cells or axons that are thought to underlie positive therapeutic outcomes in human patients. As ambitious as it sounds, the prospect of shining light into the brain of a conscious patient to map neural circuits may be just around the corner. ■

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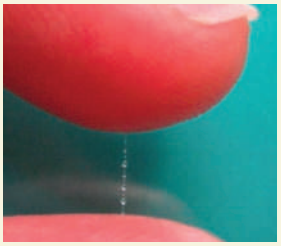
FLUID DYNAMICS

Saliva at a stretch



Reporting in *Nature Physics*, Pradeep Bhat and colleagues explain a vexing phenomenon in fluid dynamics — the 'beads-on-a-string' structures that form in viscoelastic fluids (P. P. Bhat *et al. Nature Phys.* doi:10.1038/NPHYS1682; 2010).

It's easy to observe this effect: take a blob of saliva from the top of your tongue, place it between your thumb and index finger, then slowly pull your digits apart. With practice, you'll form a thread of fluid that initially thins and drains, but that eventually forms a string of different-sized spheres (pictured). Newtonian fluids, such as water, don't do this — instead, the threads quickly break.

Saliva differs from water in containing naturally occurring polymeric molecules that make it viscoelastic. This property was thought to cause the beads-on-a-string effect, yet computer models of viscoelastic liquids couldn't reproduce the phenomenon.

Bhat *et al.* report a new computer model that factors in inertia. They find that inertia causes beads to form even on threads of low-viscosity Newtonian fluids. But in viscoelastic fluids the beads last longer, grow bigger and become more spherical. The authors' simulations also reveal that enhanced radial flow occurs at certain regions of threads, causing additional, smaller beads to form in viscoelastic fluids. They conclude that the beads-on-a-string effect results from the interplay between capillary, viscous, elastic and inertial forces.

The model offers fresh ways to explore the behaviour of materials deformed beyond their equilibrium. This is of relevance to commercial processes such as electrospinning, in which electric charges are used to draw fibres from liquids.

Andrew Mitchinson

PLANETARY SCIENCE

The birth of Saturn's baby moons

Joseph A. Burns

Simulations show that Saturn's nearby moons, after forming on the outskirts of the planet's main rings, get pushed clear of them. This model reproduces the moons' orbital locations and remarkably low densities.

Nearly six years ago, an inquisitive explorer — the Cassini spacecraft — pointed its instruments at targets in Saturn's neighbourhood for the first time. Among its numerous findings[1] was a small surprise: some of the seven diminutive satellites that gather just within and beyond the periphery of the planet's main bright rings (Fig. 1, overleaf) look curiously like flying saucers, and several have patchy, smooth surfaces. Other measurements disclosed that these tiny bodies, dubbed 'ring moons', have remarkably low densities (ranging between 0.4 and 0.7 grams per cubic centimetre), indicating that their interiors contain extensive void spaces. How might such unusual satellites come to be, and might their presence provide any insight into how Saturn's rings originated? By simultaneously simulating the evolution of the rings and of test bodies that were born at their perimeter, Charnoz and colleagues[2] present a convincing case on page 752 of this issue that the ring moons grew by the