NEUROSCIENCE

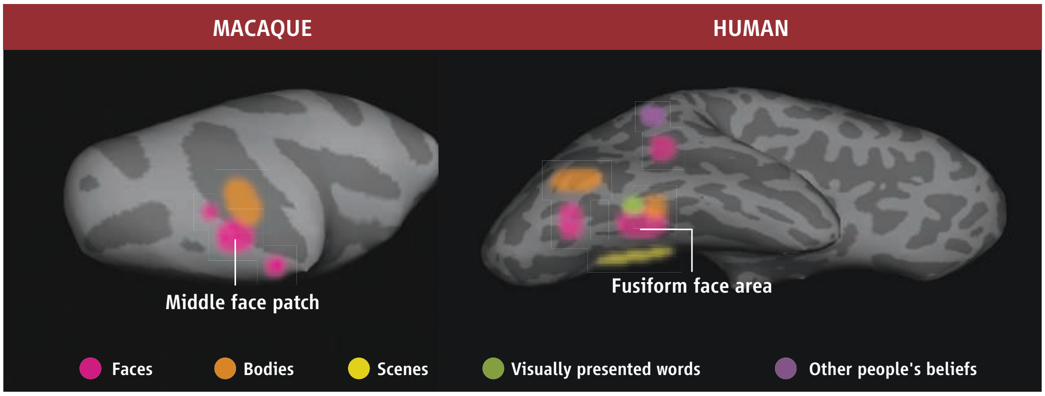
What's in a Face?

Nancy Kanwisher

Is the primate brain a generalized machine that can tackle a wide array of problems or a collection of modules, each designed for a specific task? New results suggest a modular organization, at least for specialized cognition.

Is the human brain like a Swiss Army knife (*1*), composed of special-purpose components, each tailored to solve a single specific task? Or do we instead possess a more general kind of intelligence, with minds and brains that are prepared to tackle a wide range of problems without being optimized for any of them in particular? For nearly two centuries, a debate has raged between proponents of specialized "organs" or "modules" of the mind and brain and those who support "distributed" cognitive and neural processing. A new study by Tsao *et al.* on page 670 of this issue (*2*) provides the strongest evidence to date for the Swiss Army knife view by demonstrating the extreme specificity of one cortical region for a single high-level function—face perception.

Tsao *et al.* used functional magnetic resonance imaging (fMRI), a noninvasive neuroimaging technique for studying brain activity, to identify three patches of cortex in monkeys that respond selectively to faces. They further targeted electrodes into the "middle face patch" (see the figure) to record from the individual neurons that constitute it. Their findings give astonishing evidence of functional specialization in the brain. Ninety-seven percent of visually responsive neurons in this region responded selectively to faces, and whoppingly so: On average, these neurons responded more strongly to face stimuli than to nonface stimuli by a factor of about 50. Indeed, the only nonface stimuli that elicited a significant (though very weak) response from this region were apples, clock faces, and other round objects similar in shape to faces.



Selective information processing in the brain. Regions on the surface of the macaque (**left**) and human (**right**) brain that respond selectively, as indicated. For both species, the back of the brain is at the left. Brains are not proportionally scaled to each other.

Prior evidence that face perception may be a "special" domain of cognition, with its own independent cognitive and neural machinery, comes from behavioral studies of normal and brain-damaged individuals and electrical recordings of neural activity in monkey and human brains. More recently, fMRI has revealed a particular region in the human brain where this special face perception machinery apparently resides: the fusiform face area, a blueberry-sized region on the bottom surface of the posterior right hemisphere that responds significantly more strongly when people look at faces than when they look at any other stimulus class yet tested (*3*).

The fusiform face area has served as a compelling icon for those inclined toward a modular view of mind and brain, and also as a tempting target on which opponents of this view can fix their cross-hairs. In one of the most important challenges to the claimed specificity of this brain region for faces, it has been argued that the weak but statistically significant response of the fusiform face area to nonface objects reflects the participation of this region in the representation of objects (*4*). An alternative account argues that this weak response to nonface objects simply reflects the resolution limits of the fMRI method, in which each pixel spans hundreds of thousands of neurons. This leads to an inevitable underestimation of the true selectivity of the region. The Tsao *et al.* study largely resolves this question, at least for the middle face patch in the macaque brain. By demonstrating that nearly all cells in this region respond virtually exclusively to faces, these data leave little room for a role of this region in the representation of nonface objects (*4*). Thus, Tsao *et al.* provide the strongest evidence yet for extreme specificity of a cortical region for a complex high-level function.

The new findings open up a broad new landscape of investigation. How exactly do neurons in this region code for the unique shape of each individual face? Does the neural representation of face shape differ qualitatively from the neural representation of object shape, as suggested by the behavioral literature (*5*)? How do the other two face-selective patches in monkeys differ from the one analyzed by Tsao *et al.*, and which of these face patches (if any) is homologous to the fusiform face area in humans?

More generally, which functions get their own dedicated patch of cortex, and why? In addition to face areas, other regions of the human brain (see the figure) produce similarly selective fMRI responses to bodies and scenes (*6*) and even to the representation of another person's beliefs (*7*). But such highly specialized regions may be rare in the cortex: A recent study that tested for the selectivity of 20 different object categories did not turn up any new ones (*6*). In addition to a few highly specialized mechanisms for special domains of cognition—the neural equivalent of an army knife's corkscrew, scissors, and screwdriver—the brain may also contain more general-purpose machinery that can operate across cognitive domains.

Evolutionary psychologists argue that the components of the human mind can be predicted from the specific problems faced by our ancestors on the savannah. But such considerations underconstrain the organization of the human brain. They also fail to explain observed components of the brain that could not be genetically hard-wired, such as the cortical region that responds very selectively to visually presented words and letter strings (which have arisen only very recently in human history) (*8*). Specialized neural machinery may be better predicted by the degree to which the particular task poses unique computational challenges. Perhaps we need special machinery for face perception because faces are the only stimuli requiring discrimination between thousands of exemplars that all share the same basic structure. And perhaps these "face neurons" are clustered together into their own patch of cortex to facilitate interactions between them, either to sharpen their selectivity through mutual inhibition or to medi-

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ate one of the key signatures of face processing discovered long ago by psychologists, in which the representation of each part of a face is affected by the presence of other parts of the same face (*5*).

Tsao *et al.*'s stunning data show the power of their new method: fMRI-guided neurophysiology enabled them to find the cortical "sweet spot" in which an unprecedented 97% of cells were face-selective, whereas earlier studies conducted without such guidance estimated that at most 20 to 30% of cells in any given region would be face-selective. This distinction will not be lost on neurophysiologists, and fMRI-guided neurophysiology may soon become standard practice in the field. A further contribution of the present study is the finding of parallel and consistent results from both physiology and fMRI, strengthening the evidence that responses observed by fMRI are closely tied to neural activity. Taken together, Tsao *et al.*'s findings herald a powerful new synergy between neurophysiology and imaging-based research on high-level vision.

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ASTRONOMY

Big Fields on Small Stars

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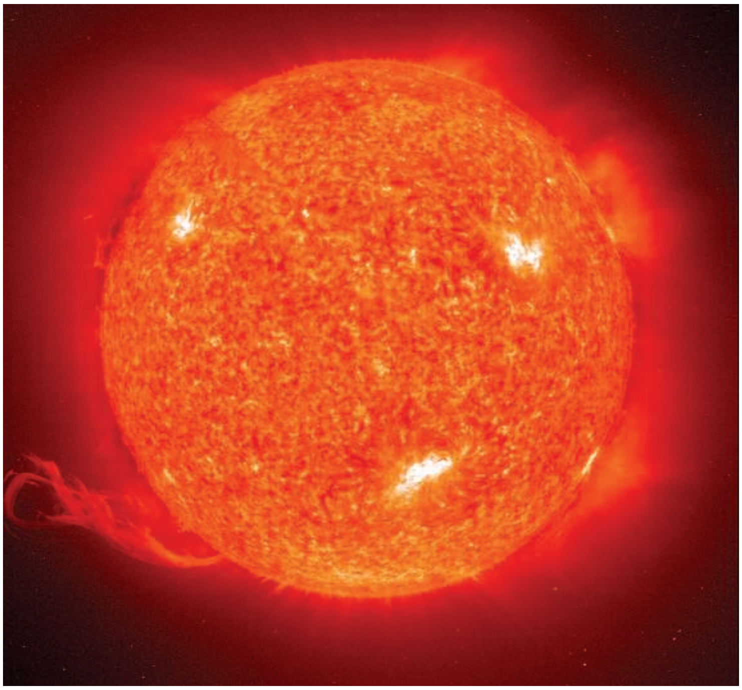
Magnetic fields from cool stars have been difficult to study. Now, Doppler imaging methods reveal unexpected details of stellar magnetism and the internal mechanisms of stars such as the Sun.

Magnetic fields are pervasive throughout the cosmos. Most of the matter in the universe is a plasma (a gas of charged particles), and thus influenced by electric currents that can give rise to magnetic fields. Such fields are responsible for phenomena as diverse as Earth's aurorae, the solar corona, spectacular bipolar jets of material shooting from newly forming stars or accreting black holes, and the magnetization that suffuses whole galaxies. Angular momentum is also pervasive in the cosmos, and combined with a moving conducting fluid or plasma it can power a magnetic dynamo. For instance, Earth's core contains one example of a self-generating magnetic dynamo, and our Sun's envelope has another. Indeed, most stars manage to generate magnetic fields, because they are rotating, convecting, conducting bodies. Nonetheless, stellar magnetic fields are notoriously difficult to study directly. On page 633 of this issue, Donati *et al.* (*1*) report an extension of a subtle technique for mapping surface magnetic fields to a very important class of stars.



Solar activity. An image of the magnetically heated surface of our Sun, obtained by the Extreme Ultraviolet Imaging Telescope (EIT) on the Solar and Heliospheric Observatory (SOHO) satellite, provides an impression of what magnetic fields on even fully convective stars may look like (*3*).

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It is often said that we live around an average star. This is not really true. Our Sun is about three times as massive as the average star, nearly twice as hot at its surface, and about 100 times as bright. These average stars ("M stars" in astronomers' parlance) are more than five times as numerous as stars like our Sun, and so constitute most of our stellar neighbors. Despite their plenitude, they have received less attention from astronomers than other stars, because until recently they were too faint to be detected by many of the diagnostic techniques applied to stars (for instance, you cannot see any of them with your naked eye even though the closest star to us is an M star).

Convection in stars arises when it is more efficient to transfer energy by mechanical motions rather than simply radiating it outward through stable plasma. The conditions that favor convection arise when the resistance (opacity) of the material to radiation is too high. This tends to happen in cooler material, where there are many more sources of opacity than in fully ionized plasma. Thus, in stars cooler than the Sun, the convection zone deepens to larger percentages of the volume.

The magnetic dynamo created by this kind of convection in our Sun reverses every 11 years, giving rise to the well-known solar cycle. It is thought to arise predominantly at the bottom of the solar convective zone (about 30% of the way to the core), where there is a shear layer between the convective envelope and radiative core. A star with mass about a third of our Sun's will be sufficiently cool that its entire interior is convective. Obviously, the magnetic dynamo must change if there is no radiative core. The expectation is that only a turbulent dynamo will remain, and such a dynamo might only generate small-scale fields (more like what is seen at the minimum of the solar cycle).

The Sun is the only star whose surface we can at present image in any detail (see the figure). For other stars, we usually make do with proxy indicators of magnetic fields related to the heating that they cause in a stellar atmosphere. This heating arises partly because the fields emerge in bipolar regions that are jostled about by the convective motions (not to mention intruded upon by other regions of opposite polarity), causing currents and magnetic dissipation. We thus have a reasonable idea of how the total magnetic flux varies with stellar parameters (through observations of stellar spectra and x-ray luminosities). To actually measure the strength of a stellar magnetic field, determine

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