

under the action of an applied stress and that includes the effect of temperature. Finally, the largest length scale involved modelling the elastic interactions between a network of dislocations, a process that becomes important at high temperature. The overall approach thus avoids the use of experimental data and seeks to predict the relationship between stress and strain rate for a single crystal of magnesium oxide at high temperature and pressure without assuming a particular functional form for that relationship.

Because experiments are time limited, accessible measurable strain rates are typically around 10^{-6} per second (where a sample doubles in length in about two weeks). This is much higher than the maximum strain rate expected in the mantle (perhaps 10^{-12} s $^{-1}$; at this rate, a sample would take more than 30,000 years to double in length). The usual approach for dealing with such low strain rates is to extrapolate experimental data using a power law — a straight line on a plot of the logarithm of stress against the logarithm of the strain rate. This is assumed to be valid over many orders of magnitude. Cordier and colleagues' multi-scale model² makes no such assumption, but, importantly, it reproduces laboratory data at high strain rate over a wide range of temperatures even though these data are not used in the model.

The authors' model can also be used at the low strain rate found in the mantle, allowing the power-law assumption to be tested. Cordier *et al.* found that results from the model differ greatly from the usual power-law extrapolation of laboratory data. The model predicts that magnesium oxide deforming under lower-mantle conditions is significantly weaker than the power-law extrapolation would suggest (Fig. 1).

The most direct implication of this work is that methods used to extrapolate experimental data need to be re-examined. It might be possible to find a way of using experimental data showing the dependence of strain rate on stress, over a wide range of temperatures, to parameterize a non-power-law description of deformation that is consistent with the weakening at very low strain rates predicted by the multi-scale modelling. It remains to be seen whether experiments performed at high enough strain rates for them to be completed in a realistic time-frame can provide enough information to do this.

Magnesium oxide makes up only about 20% of the lower mantle, which is dominated by silicate minerals. A pivotal question is whether Cordier and colleagues' model will be as successful in describing the deformation of these structurally more complex materials as it is for magnesium oxide. One consideration is that the melting point of the silicate phases is lower than that of magnesium oxide, opening up the possibility

that deformation is controlled by the motion of isolated atoms rather than by the movement of dislocations⁶. Which of these two processes controls deformation is crucially dependent on the size of individual crystal grains in lower-mantle rocks, a key geophysical parameter that has stubbornly resisted elucidation.

A second concern is that an increasing list of materials, including some that share the structure adopted by silicates in the lower mantle, show dislocations that have a complex, non-planar structure not found in magnesium oxide⁷. If such dislocations occur in silicates in the lower mantle, the authors' multi-scale model would need modification to properly capture the deformation process.

We now have the tools needed to simulate, from first-principles calculations, the deformation of minerals in the lower mantle by the two most likely underlying mechanisms — the motion of atoms⁶ and of dislocations². With careful handling of the interaction between adjacent crystals, it may at last be feasible to simulate mantle convection with full feedback between geodynamics, deformation and thermodynamics. These more realistic

geodynamical simulations would be expected to exhibit history-dependent deformation and strain weakening. If, for example, regions of strong mantle material surrounded by weak shear zones were to develop, the mantle could resist mixing and allow chemical heterogeneity to be retained over geological time. Such effects complicate our view of mantle convection, but detailed determination of the consequences must await the results of such simulations. ■

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COGNITION

Your face looks familiar

Paper wasps of the species *Polistes fuscatus* live in strict hierarchical societies in which the ability to identify superiors and subordinates is crucial. Like humans, these insects have a cognitive tool kit for recognizing familiar faces.

LARS CHITTKA & ADRIAN DYER

The ability to recognize individuals can convey significant benefits to social animals. In humans, the capacity to recognize different faces is crucial for making individual behaviour predictable for other members of a group — for keeping track of who is aggressive, bold or wise — and so for knowing everyone's place in a family or society. Moreover, there is strong evidence^{1,2} that primate brains contain specialized modules for face processing and recognition. Writing in *Science*, Sheehan and Tibbetts³ present evidence that an insect, the paper wasp *Polistes fuscatus*, not only recognizes the faces of individuals of the same species, but is a veritable expert at face discrimination.

Individual queens of many social insects, including *Polistes metricus* — a species closely related to *P. fuscatus* — found colonies in the spring, a perilous and challenging enterprise for a single insect. By contrast, several *P. fuscatus* queens typically join forces to build, defend and provide for a new nest. This boosts the chances of the project's success, but, for many

of the hopeful foundresses, there is a price to pay: a linear hierarchy is established through a series of one-on-one fights. Consequently, the strongest queen dominates egg-laying, whereas subordinates do more menial tasks. After a duel, individuals recognize their opponents by their distinct facial markings, which helps to avoid the repetition of potentially costly battles.

Sheehan and Tibbetts studied face recognition in *P. fuscatus* and *P. metricus*. They trained the insects to choose one of two arms of a maze, each marked by an image (Fig. 1). If the wasp turned to the 'wrong' image, it experienced an electric shock, whereas choosing the 'correct' arm provided safety. The image pairs consisted of normal wasp faces, manipulated wasp faces, simple geometric patterns or caterpillars — the typical prey of these wasps.

The authors report that the face-learning ability of *P. fuscatus* was greater than that of *P. metricus*. Moreover, *P. fuscatus* wasps learned to recognize wasp faces more quickly and more accurately than they did other image types. Intriguingly, this insect had difficulties recognizing faces that lacked antennae or that

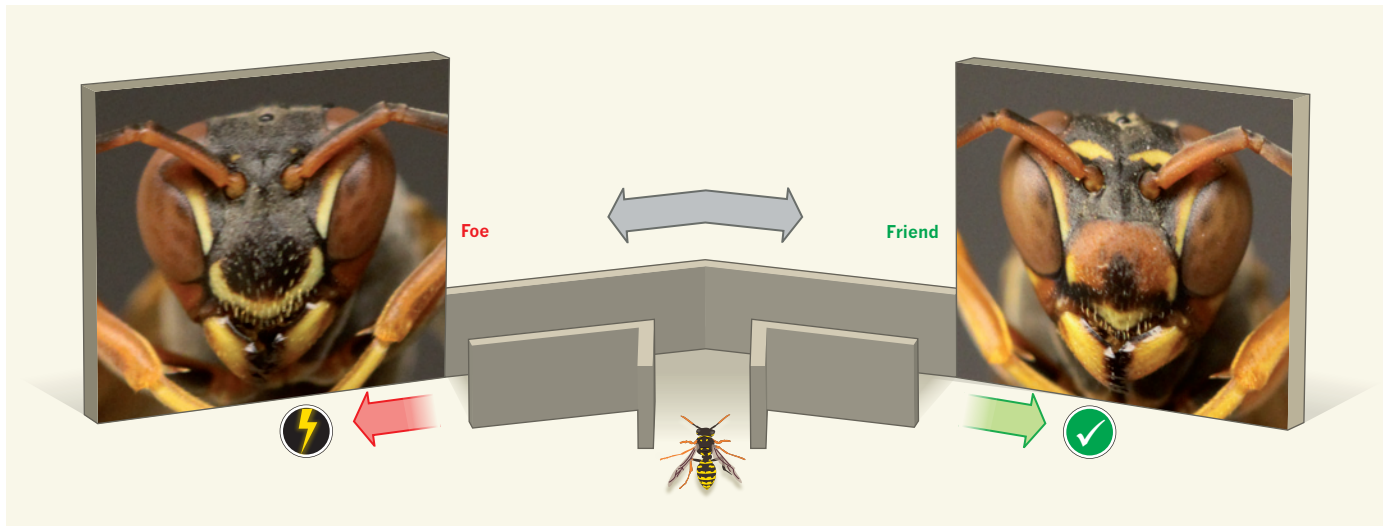


Figure 1 | Face learning by paper wasps. Sheehan and Tibbetts³ tested the learning abilities of two closely related wasp species, *Polistes fuscatus* and *P. metricus*, in a T-shaped maze. When an individual wasp entered the maze, it had two possible routes to take, which were marked by different images. One (Foe) resulted in punishment with an electric shock, whereas the other (Friend) granted entry to a safety zone. The authors found

that *P. fuscatus* is especially skilled at learning to distinguish between correctly configured facial patterns — a unique adaptation to its social environment, in which these wasps use face recognition to establish and enforce dominance hierarchies. In *P. metricus*, individual recognition is not part of social life, and this species failed the face-learning task. (Images, M. J. Sheehan, Univ. Michigan.)

contained scrambled features. This indicates that face learning in *P. fuscatus* is specific to correctly configured faces, and cannot be explained by a general pattern-recognition system.

Because Sheehan and Tibbetts³ used wasps caught in the wild, it is not clear whether the insects' expertise at face recognition was acquired through evolution, individual experience before capture or an interaction of both. Nonetheless, at the behavioural level, face recognition in *P. fuscatus* shares some features with that in humans. For humans, too, the configuration of facial features is important for reliable recognition⁴. Elemental features such as eyes, nose and mouth are not processed individually but as a whole, and their rearrangement significantly impairs recognition performance.

Several types of processing of facial configurations that have been identified in humans could be explored in wasps. These include detection of a face on the basis of its overall arrangement of features; face processing where certain elemental features are bound together; and sensitivity to second-order relationships, whereby the relative distances between various elemental features enhance recognition⁵.

Neurophysiological investigation of specialized brain areas mediating face processing in humans^{1,6} and monkeys² confirmed the existence of bespoke neural mechanisms for analysing the arrangement of facial features. Studies in other mammals⁷ also indicated that the ability to process configural face information involves specialized neural circuitry and extensive experience. However, work in insects on visual processing of compound patterns (including face images) suggests⁸ that species without specialized face-processing abilities

may also be capable of configural processing. In terms of gross neuroanatomy⁹, there are no discernible differences between the visual system of *P. fuscatus* and those of related species that do not use face recognition.

It is therefore likely that neural circuitry similar to that used by insects for prey recognition is co-opted in *P. fuscatus* for face recognition owing to the insect's social lifestyle. This might require only fairly minor adjustments in neural circuitry to embed visual pattern recognition into the appropriate (social) context. Sheehan and Tibbetts's observation³ that *P. metricus* lacks specialized face recognition lends further support to the view that specialized cognitive capacities can evolve relatively easily in response to pertinent selection pressures.

The finding that a small-brained insect shares the ability to recognize faces with humans and other primates may come as a surprise to adherents of the 'social brain' hypothesis¹⁰ — the idea that group-living and complex social interactions require large brains. However, in asking questions about brain size and cognitive capacity, one must focus on what the computational nature of the task is, and what neural circuitry is actually required to accomplish it. In this view, the specific task that requires a large brain has yet to be discovered.

Analyses of neuronal networks¹¹ show that reliable face recognition can be achieved with a network of only a few hundred neurons — a circuitry that could be easily accommodated in an insect brain — especially because much of the neural hardware for pattern recognition would also be used for other visual tasks such as recognition of landmarks or prey. Small-brained invertebrates, such as insects, are thus exceptionally useful models for studying how

social and cognitive abilities can be mediated by modest neural circuitry¹², and of the evolutionary adjustments necessary to generate such abilities. As for bigger brains, many of their advantages might relate to higher memory storage capacity (equivalent to bigger hard drives rather than better processors), more parallel processing, or more precision and detail in sensory information, but not necessarily to more complex cognitive processes¹². ■

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