

distinct phenomena. Antimalarial antibodies defined by agglutination, enzyme-linked immunosorbent assay (data not shown) or surface immunofluorescence (data not shown) were not associated with the presence or absence of infection.

Anti-adhesion antibodies against CSA-binding parasites differ from antibodies against parasites with other binding phenotypes. In studies of CD36-binding parasites, sera were variably effective⁴⁻⁶ and blocked adhesion strain-specifically; the inhibition of adhesion may have been associated with agglutination, which can interfere with adhesion. Our data indicate that anti-adhesion antibodies against CSA-binding parasites uniformly develop in multigravid women from holoendemic areas, appear in Asian and African women, block adhesion in a strain-independent manner, and are distinct from agglutinating antibodies.

We have shown that women with anti-adhesion antibodies against CSA-binding parasites are protected from malaria infection during pregnancy. Because women have limited exposure to the CSA-binding parasite before first gestation, primigravidas lack anti-adhesion antibodies against this parasite subpopulation. We propose that this absence of anti-adhesion antibodies increases susceptibility to malaria during first pregnancies. Further research is required to examine the association between anti-adhesion antibodies and pregnancy outcome, and, most important, to identify PfCSA-L as the next step towards developing a vaccine. An anti-adhesion vaccine that conferred protection against maternal malaria would benefit millions of pregnant women and infants in the tropics, and should be a public health priority.

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Object recognition can drive motion perception

When two spatially separated spots of light are flashed in rapid succession, apparent motion is seen between them¹⁻³. We extended this phenomenon by photographing a face and producing from it a fragmented 'puzzle picture' or 'Mooney face' in which the face is not initially visible (Fig. 1, left; frame 1) but is seen after 15 to 60 seconds⁴. Another photograph of the same face seen in profile was used to produce a second Mooney face (Fig. 1, right; frame 2). When the two images were alternated, naive subjects at first saw random, incoherent, two-dimensional (2D) motion between the fragments. But once the face was recognized, it was perceived to rotate unambiguously in three dimensions. We conclude that complex image tokens set up by perceptual learning can drive perception of apparent motion.

To what extent are different aspects of perception mediated by specialized modules⁵⁻⁸ in the brain? Attention can influence the way in which corresponding points are seen to move³ and, in ambiguous, bi-stable displays, people tend to see 'plausible' trajectories (for example, a bomb is more likely to be seen going down rather than up⁹). But it is usually assumed that these are weak second-order effects, no more than a small bias in the perceived direction of motion.

Cells in area MT of the monkey brain respond to apparent motion¹⁰ and there is psychophysical evidence that primitive, rather than sophisticated, visual features are used for motion correspondence¹¹. As a result, most computational models of motion perception emphasize a stronger modular approach^{12,13}, arguing that motion correspondence is not influenced by high-level object knowledge and semantics. For instance, it is easy to see a pig's face transforming into a human face even though this is logically absurd.

Here we use a new type of apparent-motion display to investigate directly how perceptual learning and high-level object knowledge are involved in motion processing. First, we illuminated the face of a model looking at the camera lens with a single strong light source. We then photographed the face and digitized the image to obtain a fragmented puzzle picture (Fig. 1, left). The model then rotated his face by 45 degrees (or 90 degrees) and a second image was made using the same procedure (Fig. 1, right). A set of four pairs of such images was made of four different faces. The direction of illumination and degree of head rotation were chosen to eliminate local matches between the shadows and to optimize the difference between the appearance of the images before and after perceptual learning⁴.

Naive subjects could often not see the faces in these images. Of 28 subjects, 17 could not see the face initially in at least one of the four sets of photographs, and four of these subjects could not do so in two. These 17 volunteers were first shown various demonstrations of apparent motion (but not of faces) to familiarize them with the illusion. They were then shown frames 1 and 2 of the images in which no face was perceived, alternated at 3 Hz (ISI = 0) for 20 seconds, and asked to describe the perceived direction of motion, if any. The subjects saw either random chaotic motion or motion along arbitrary 2D trajectories that often varied from trial to trial (in 20 of 21 experimental sessions). When asked explicitly if they saw any 3D motion, 16 subjects said they had not; the seventeenth subject immediately saw a face rotate in one of the displays as soon as the two frames were alternated.

The film sequence was then stopped and the same subjects were asked whether they could see a human face, a prompt that always resulted in the face being seen after 10 to 30 seconds (we often had to resort to pointing to individual features after 30 seconds). Remarkably, when the same two frames were alternated, all subjects in all



Figure 1 Two views of a 'Mooney'-type face produced by digitizing a video image. Left, frame 1; right, frame 2. A demonstration can be produced by showing the two frames alternately as an upside-down movie; nearly all subjects see 2D movement. But if the same movie is viewed upright or the subjects are told it is a face, they invariably see rigid 3D rotation.

trials saw 3D rotation of the face, from frontal to semiprofile or profile. No 2D expansion, contraction or chaotic incoherent motion was ever seen. Because the display was exactly the same but the perceived motion trajectory had changed completely, we conclude that high-level object representations can drive apparent motion. In particular, a temporary 'object' (or extended contours forming portions of it) created exclusively by perceptual learning can provide an input for apparent motion. The meaning of the perceived configuration therefore helps to eliminate an infinite set of false matches between the fragments, allowing motion correspondence to be established correctly between the two views of the face.

Similar effects were seen with other puzzle pictures, such as a hidden dalmatian dog¹⁴, with the dog sitting and standing in alternate frames. When the two frames were alternated, subjects initially saw random 2D motion, but once the dog was seen it was perceived to sit and stand alternately. This effect is particularly remarkable because the second image was made using a completely different dog with different spots, so no rigid transformation was possible between the two images.

Taken together, these observations suggest that strong interactions occur between perceptual modules concerned with motion (for example, in area V5)⁵ and those involved in high-level object recognition (for example, in area IT)⁴. The strictly hierarchical, modular models of perception popularized by computer scientists should therefore be replaced by a more dynamic view. From every stage in the hierarchy, partial answers may be sent back to bias the processing in earlier stages.

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Preserving tardigrades under pressure

When an animal is exposed to high hydrostatic pressure, its cellular membranes^{1,2}, proteins^{3–5} and DNA⁶ are damaged. At pressures of around 30 megapascals (MPa), proliferation and metabolism in microorganisms stops; at 300 MPa, most bacteria and multicellular organisms die. But here we show that, in perfluorocarbon at pressures as high as 600 MPa, small terrestrial animals known as tardigrades can survive in a dehydrated state.

Terrestrial tardigrades become immobile and shrink into a form known as the 'tun' state when the humidity decreases. In this state, they can survive extreme temperatures, as low as $-253\text{ }^{\circ}\text{C}$ or as high as $151\text{ }^{\circ}\text{C}$, as well as exposure to a vacuum or to X-rays^{7–10}. We have now tested the ability of the tardigrades *Macrobiotus occidentalis* (order Eutardigrada) and *Echiniscus japonicus* (Heterotardigrada) to survive under extraordinarily high hydrostatic pressures.

We sealed *M. occidentalis* tardigrades in a small plastic container (6 ml) placed inside a pressure capsule (R7K-3-10, Yamamoto Suiatu Kougyousho) and compressed using water as the pressure medium. The outside temperature was $21\text{ }^{\circ}\text{C}$ and the water temperature inside the capsule was $25\text{ }^{\circ}\text{C}$; stepped hydrostatic pressures were applied for 20 minutes at a time (100, 200, 300, 400, 500 and 600 MPa). Pressure was increased by 100 MPa per minute and then decreased at the same rate. After decompression, *M. occidentalis* was removed from the capsule

and examined under a light microscope, which revealed that all organisms died at pressures over 200 MPa (Fig. 1).

We then investigated whether tardigrades could acquire pressure resistance in the tun state (a process known as anhydrobiosis) by dehydrating them before applying pressure. *M. occidentalis* and *E. japonicus* were dehydrated on filter paper in Petri dishes for more than 24 hours, when the relative humidity in the dishes dropped from 70–80% to 10–30%. To prevent the tardigrades from rehydrating during compression, we used an inert solvent, perfluorocarbon (C_8F_{18} Fluorinate PC77, Sumitomo 3M), as the pressure medium instead of water. Tardigrades were then removed from the pressure capsule and soaked in water to rinse off the perfluorocarbon. One hour later, we confirmed that they had changed from the tun state to the active state.

To test whether the perfluorocarbon increased the survival of tardigrades exposed to high hydrostatic pressure, we subjected tardigrades in perfluorocarbon, which were still in the active state, to the same hydrostatic pressure changes. All active-state tardigrades were dead at pressures above 200 MPa.

We evaluated the data at 600 MPa for the group ($n = 20$) in the tun state in perfluorocarbon and in the active state in water and perfluorocarbon. The survival rate of *M. occidentalis* was 95% at 600 MPa (Fig. 1), and there was a difference between active-state and tun-state animals ($P < 0.01$; chi-squared). The survival rate of *E. japonicus* was 80%, as some animals had died and their fluid had leaked onto the filter paper, which we attributed to inadequate

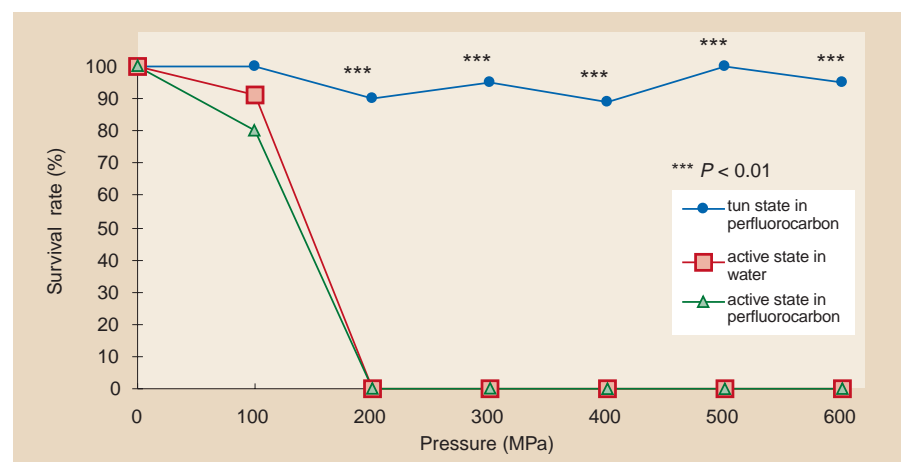


Figure 1 Survival rate of *Macrobiotus occidentalis* after exposure to high hydrostatic pressure. Before compression (100 MPa min^{-1}), tardigrades were either in the tun state (dehydrated) in perfluorocarbon, or in the active state in water or perfluorocarbon. Either water or perfluorocarbon was used as pressure medium. An hour after high hydrostatic pressure was maintained for 20 minutes and decompression to -100 MPa min^{-1} , the animals were soaked in distilled water for an hour, and those in the active state were examined with an optical microscope (magnification, $\times 40$). When animals in the tun state were exposed to 100–600 MPa in perfluorocarbon, a high survival rate was obtained. The survival rate of active-state animals in perfluorocarbon is 80% at 100 MPa and 0% at pressures greater than 200 MPa. This survival rate at 100 MPa was lower than the 91% obtained using water at 100 MPa, so perfluorocarbon did not increase the survival rate.