

it would be difficult to prove our ideas by such methods, giving as a single example the presumed absence of the Land effect in V1 neurons. Pollen is correct in pointing out that this argument deals with only one or a few types of neurons in V1. It may also be true that the very high spatial frequencies that we cannot see⁴ may excite solely inhibitory cells in V1, though we doubt this. It might be possible to test this by recording from alert macaque monkeys, but it would not be easy.

We are grateful to Pollen for drawing our attention to the work of Horton and Hoyt⁵. This shows rather clearly that for a patient with a quadrantic visual field defect, who is blind within that part of the visual field, the relevant portion of V1 is largely, if not entirely, intact.

This result might initially seem to support our hypothesis very strongly. However, we agree with Pollen that although V1 is structurally intact, it is not receiving all its usual inputs, especially those coming back from V2 and V3, because the relevant parts of these regions are damaged. If these back-pathways are essential for visual awareness, Horton and Hoyt's observations would not support our hypothesis; however, Pollen gives no evidence that a person would be totally blind without these particular back-pathways. Until the exact impact of such pathways is determined experimentally, the matter must remain open. If these

pathways (in a macaque or lower mammal) were knocked out, and the animal could still see, then cases similar to those reported by Horton and Hoyt, provided there was no subcortical damage, would strongly support our hypothesis.

We agree with Pollen that if the connections from (surviving) V1 to subcortical areas were intact in such patients, the results would show that those connections are not, by themselves, sufficient to subserve visual awareness. Of course, it may be that, despite this, one or more of these connections is necessary for visual awareness.

Several papers, both on blindsight in normal observers¹⁵ and the McCollough effect in patients who cannot see orientation^{16,17}, are compatible with the idea that striate cortex activity by itself can influence behaviour without producing awareness, but this evidence is not strong enough to prove our hypothesis directly.

In summary, we regard our hypothesis as plausible but at present difficult to prove. Pollen may not like our ideas, but he has produced no evidence that decisively disproves them.

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The amygdala and emotional memory

SIR — Animal studies indicate that memory storage for events that arouse emotions involves neurobiological processes consisting, at their simplest, of activation of β -adrenergic receptors and the amygdaloid complex¹. Recently, we reported that in normal human subjects, β -adrenergic blockade selectively impaired long-term (1 week) memory for an emotionally arousing short story². We report here parallel results from a patient with impaired function of the amygdaloid complex.

The patient (B.P.) suffers from Urbach-Wiethe disease, an extremely rare hereditary disorder that has produced bilateral brain damage confined to the amygdaloid complex region (Fig. 1), with no evidence of the seizures seen in some Urbach-Wiethe patients³. Recent psychological tests show B.P. to be in the normal range for many cognitive functions, including atten-

tion, intelligence and short-term memory⁴.

In the present investigation, B.P. was told a short story, presented as a brief, narrated slide show, about a young boy walking with



FIG. 1 Coronal computer tomography scan showing bilateral mineralization in the amygdaloid complex in patient B.P. Additional brain-scan images have been reported elsewhere⁴. (Photograph courtesy of Neurological University-Clinic, Knappschaftskrankenhaus Bochum, Germany.)

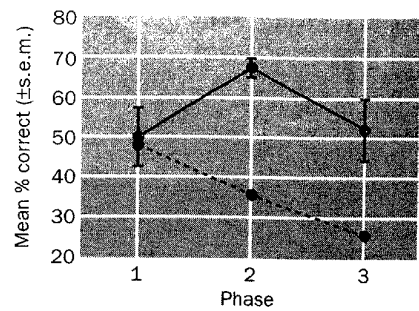


FIG. 2 Memory test performance for controls (solid line; $n=6$) and patient B.P. (dotted line). Controls were matched to B.P. for age (mean age, 34.8 ± 1.5 yr; B.P. age, 37 yr) and for education (mean number of school years, 10.5 ± 0.67 ; B.P., 10 yr). Controls show the expected increase in memory for phase 2 of the story, in which the strong emotional elements were introduced (phase 3 is the final phase of the story).

his mother to visit his father at work. The story was slightly modified from that used in our previous report (for example, it was translated into German), but retained the essential features of the original version. At one phase of the story, emotional events (involving severe injuries to the boy and graphic pictures after he is involved in a terrible traffic accident) are introduced.

Consistent with our previous report, results from the German control subjects indicate that memory for this phase of the story (phase 2) is consistently superior to that of the relatively unemotional initial story phase 1 (as assessed with a multiple-choice recognition test one week later; Fig. 2). In sharp contrast, B.P. showed no evidence of enhanced memory for phase 2 of the story despite normal memory for story phase 1. B.P.'s self-assessed emotional reaction to the story (determined immediately after viewing the story) was similar to that of the controls: mean emotional rating of the story (on a scale of 0 to 10) for controls was 7.25 ± 1.2 ; B.P. rated his reaction to the story at 8. Thus, B.P. failed to show the normal increase in memory associated with emotional arousal despite a normal self-assessed emotional reaction to the story.

These results are consistent with earlier findings from this and another Urbach-Wiethe patient indicating selective impairment of memory for emotional material^{4,5}. The results may be related to demonstrations of impaired recognition of emotion in faces by patients with lesions of the amygdaloid complex^{6,7}, as well as to the

- McGaugh, J. L. *et al. Behav. Brain Res.* **58**, 81–90 (1993).
- Cahill, L., Prins, B., Weber, M. & McGaugh, J. L. *Nature* **371**, 702–704 (1994).
- Tranel, D. & Hyman, B. T. *Archs Neurol., Chicago* **47**, 349–355 (1990).
- Markowitsch, H. *et al. NeuroReport* **5**, 1349–1352 (1994).
- Babinsky, R. *et al. Behav. Neurol.* **6**, 167–170 (1993).
- Adolphs, R. *et al. Nature* **372**, 669–672 (1994).
- Young, A. W. *et al. Brain* **118**, 15–24 (1995).
- Bagshaw, M. H. & Coppock, H. W. *Expl Neurol.* **20**, 188–196 (1968).
- Bechara, A. *et al. Science* **269**, 1115–1118 (1995).

established role of this brain region in conditioning of autonomic processes during emotional learning situations^{8,9}.

Considered together with our previous study², these findings support the view that the influence of emotional arousal on conscious, long-term memory in humans involves β -adrenergic receptor activation and influences mediated by the amygdaloid complex. Furthermore these processes seem not to be required for normal retention in non-emotionally arousing circumstances.

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A methanotrophic carnivorous sponge

SIR — Associations between methanotrophic bacteria and several species of mytilids and a pogonophore have been described in deep-sea communities surrounding hydrothermal vents and cold seeps¹. We report here a new symbiosis between a sponge and methanotrophic bacteria. The $\delta^{13}\text{C}$ values and distribution indicate that the sponge is nutritionally reliant on its methanotrophic symbionts. Ultrastructural evidence indicates intracellular digestion of the bacteria. Intracellular symbionts were found in brooded embryos, indicating direct transmission of the symbionts between generations.

The sponge, *Cladorhiza* sp., belongs to a unique deep-sea family, Cladorhizidae (Demospongiae), which are carnivorous, and lack an aquiferous system². The specimens were collected from a mud volcano in the Barbados Trench at a depth of 4,943 m. Large aggregations of hundreds of individuals (up to 1.5 m in diameter and 40 cm high) were found around the periphery of the volcano's eye, where the highest concentrations of methane were documented

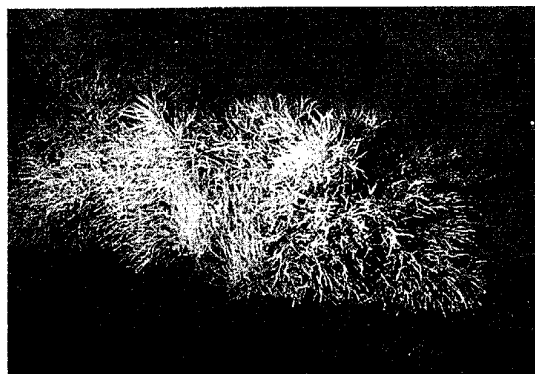


FIG. 1 Large bush of cladorhizid sponge observed with the submersible *Nautille* at 4,943 m in the mud volcano Atalante, in the Barbados Trench, during the MANON cruise. The bushes were most abundant and larger around the volcano eye where large amounts of methane were detected.



FIG. 2 Transmission electron micrographs of microsymbionts within the surface cells of the embryo. *a*, Two bacterial types (arrows). Scale bar, 2.7 μm . *b*, Magnification of a methanotrophic symbiont with stacked lamellae. Unlike bacteria inside somatic cells, there is no evidence of symbiont degradation in the embryo cells. Scale bar, 0.3 μm .

ed³ (Fig. 1). Before this discovery, cladorhizids were known to occur only in low densities as discrete individuals.

Two ultrastructural types of symbiotic bacteria were observed in the sponge tissue (Fig. 2). (1) Coccoid cells with stacked intracytoplasmic membranes and electron-lucent droplets. This morphology is typical of some methanotrophic bacteria, including methanotrophic symbionts described in other invertebrates. (2) Smaller, oval-to-rod-shaped cells. Both symbionts occurred intercellularly, apparently healthy, with frequent division stages, and intracellularly in phagocytic cells in various stages of degradation, suggesting a nutritional relationship between host and symbionts.

Many symbionts were also observed within flattened cells at the surface of embryos. In this location, no degenerating symbionts were apparent. This suggests a mechanism for direct transmission of the symbionts between generations and is reminiscent of littoral 'bacteriosponges', where bacteria are transmitted between generations in oocytes.

Sponge tissues were tested for the presence of key enzymes of methylotrophic and chemoautotrophic sulphur-oxidizing bacteria. Significant methanol dehydrogenase activity was found, indicating the presence of abundant methanotrophic symbionts. Low activities

of ribulose 1,5-bisphosphate (RuBP) carboxylase were detected, which could be due to type x methanotrophs, low activity in chemoautotrophic symbionts, or surface bacteria. Neither ATP sulphurylase nor adenosine-5'-phosphosulphonate reductase activities were detectable.

The very negative tissue $\delta^{13}\text{C}$ values (from -48.4 to -48.8‰ in three samples) are also consistent with the presence of methanotrophic symbionts. The relatively light tissue $\delta^{15}\text{N}$ values (+2.0 to 2.9‰) are within the range reported for other vent and seep fauna, and reflect significant input of organic nitrogen of local origin⁴.

These observations indicate that the symbionts are methanotrophic and suggest that the sponge derives some of its nutrition from the intracellular digestion of the symbionts. A similar mechanism has been suggested for a variety of other chemoautotrophic and methanotrophic symbioses¹, as well as for littoral 'bacteriosponges' with heterotrophic symbionts⁵.

The sponge morphology, erect with branching processes bearing a cover of hook-like spicules, suggests they may also feed on swimming prey, as do other cladorhizids². This was supported by the presence of debris from small crustaceans on the sponges. The relative importance of carnivory and methanotrophy in sponge nutrition cannot be evaluated, but it is unlikely that such aggregations of carnivorous sponges could survive in the deep sea without a nutritional symbiosis.

Carnivory has allowed cladorhizid sponges to colonize the deepest oceans, although they are normally small and rare. The association with methanotrophic bacteria, with their unusual feeding strategy, allows a large biomass, and illustrates the extreme adaptability of *Porifera*.

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1. Nelson, D. C. & Fisher, C. R. in *Microbiology of Deep-Sea Hydrothermal Vent Habitats* (ed. Karl, D. M.) 125-168 (CRC Press, Boca Raton, FL, 1995).
2. Vacelet, J. & Boury-Esnault, N. *Nature* **373**, 333-335 (1995).
3. Le Pichon, X. et al. *J. geophys. Res.* **95**, 8931-8943 (1990).
4. Fisher, C. R. et al. *Mar. Ecol. Prog. Ser.* **103**, 45-55 (1994).
5. Reisinger, H. M. *P.S.Z.N.I. mar. Ecol.* **2**, 273-293 (1981).