

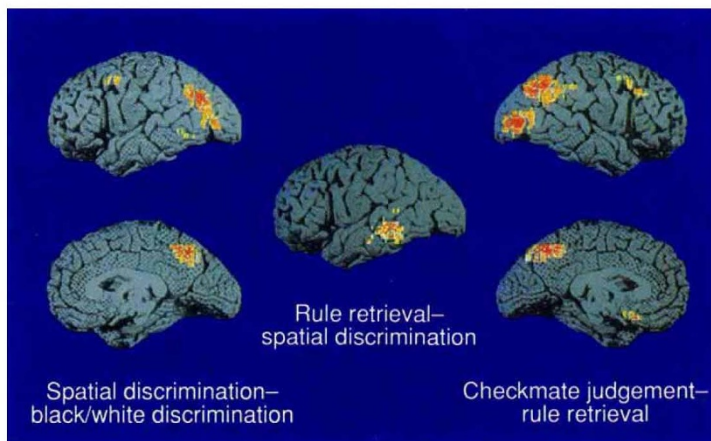
Brain activity in chess playing

SIR — There is widespread interest in identifying the topography of the neural networks subserving problem solving in humans. One potentially fruitful approach is to use functional neuroimaging techniques in conjunction with cognitive tasks¹. Chess is an example of such a task², and we have administered chess problems in conjunction with [¹⁵O]water-positron emission tomography (PET) to identify the neural network(s) activated in this process³.

The stimuli for all the task conditions were black-and-white chess diagrams presented on a computer screen. To isolate brain activation changes related to the use of specific cognitive processes, we devised four conditions arranged in a subtractive hierarchy: (1) black/white discrimination, in which subjects had to indicate whether or not there were chessmen of a given colour on the board; (2) spatial discrimination, in which an *X* was displayed in one of the board's squares and subjects had to identify the colour of the chessman closest to the *X*; (3) rule retrieval, in which subjects analysed a simple, single move, in responding to questions like "can the white knight capture a black rook?"; and (4) checkmate judgement, in which the subjects had to determine whether the player with a given colour could checkmate in one move. All answers were indicated by pressing response keys labelled yes or no. Ten right-handed males who had played chess for more than 4 years and were regularly participating in chess tournaments volunteered for this study.

When the results of the black/white discrimination condition were subtracted from the spatial discrimination condition, brain activation was observed bilaterally (see figure for a visual rendering of all the analyses) at the parieto-occipital lobe junction (areas 7 and 19), at the left middle temporal gyrus, and at the left superior premotor cortex. Extrastriate visual cortical areas are mainly organized around two anatomically separate and functionally specialized processing streams: a ventral occipito-temporal pathway for identifying objects; and a dorsal occipito-parietal pathway for perceiving the spatial relations between objects^{4,5}. The black/white discrimination task only

required the subject to process figure-ground separation and discriminate between black and white chess pieces. The extra visual analysis required by the spatial discrimination condition explains the dorsal pathway activity. Activity in area 7 (both in the superior parietal lobule and in the medial superior parietal cortex) has



Cerebral regions associated with cognitive components resulting from subtraction between the four tasks. PET images were reconstructed by bilinear interpolation in the axial (z) dimension to produce transaxial planes. Data were displayed in a 128×128×43 voxel matrix, each voxel having similar dimensions in each of the three axes. Any roll and/or yaw misalignment between scans was corrected based on visual inspection independently by P.N. and P.P. For each comparison an image of the pixel *t*-values was created, constituting the statistical parametric map (SPM{t}). The omnibus significance of these *t*-statistical parametric maps was assessed by comparing the expected and observed number of pixels above a significance threshold of $P=0.001$ (ref. 9). Only SPMs that were significant in the omnibus sense (at $P<0.001$) are reported. To illustrate the distribution of the main sites of activation, significant areas of activation for each subtraction condition are rendered on the lateral and (when appropriate) the medial surface of the brain used in ref. 10.

been repeatedly associated with spatial vision and with shifting spatial attention. We also found activation in a region of the left superior premotor cortex (superior area 6) which previous studies suggested was related to preparing a response to a selected peripheral location.

Subtraction of the spatial discrimination condition from the rule retrieval condition yielded several foci located

along the lateral, the inferior, and the medial aspects of the left temporal lobe, the latter being mainly due to activation of the left hippocampus. We suggest that the retrieval of move sequences paired with a particular chess piece was responsible for the hippocampus and temporal lobe activation⁶. A small peak of activation was also found in the inferior part of the post-central gyrus as well as in the cerebellum, which has recently been implicated in cognitive processing⁷.

In the subtraction of rule retrieval from checkmate the differential activity was confined to two large areas, the junction between the occipital and the parietal lobe, and the frontal lobe. We attribute the bilateral focus of activation we recorded at the occipito-parietal junction (areas 7, 18 and 19) to the act of generating sequential board images and to attentional shifts across the images. Activation recorded in the frontal eye fields (area 8) might be associated with an increase in extraocular movements during the instantiation of various endgame strategies. We also found increased activity in two prefrontal regions, one located in the left orbito-frontal cortex, and the second in the right prefrontal cortex. We believe that these two regions of activation subservise managerial knowledge required for the planning and sequential execution of endgame strategies⁸.

We have demonstrated that solving a complex problem calls for the activity of a network of several interrelated, but functionally distinct, cerebral areas. The use of neuroimaging techniques such as PET, carefully coupled with distinctive information-processing demands, can help disentangle the role of each of these areas in human problem-solving activity.

Paolo Nichelli*

Jordan Grafman[†]

Pietro Pietrini[‡]

David Alway

John C. Carton

Robert Miletich

*Cognitive Neuroscience Section,
Medical Neurology Branch,
National Institute of Neurological
Disorders and Stroke,
Bldg 10; Room 5S209,
National Institute of Aging[†],
National Institutes of Health,
Bethesda, Maryland 20892, USA*

*Also at: Clinica Neurologica, Univ. Modena, Italy.

[†]Author for correspondence.

- Roland, P. E. & Friberg, L. J. *Neurophysiol.* **53**, 1219–1243 (1985).
- Charness, N. in *Towards a General Theory of Expertise: Prospects and Limits* (eds Ericsson, K. A. & Smith, J.) 39–63 (Cambridge University Press, 1991).
- Raichle, M. E. in *Handbook of Physiology, Section 1: The Nervous System* **5**, 643–674 (1987).
- Desimone, R. & Ungerleider, L. G. in *Handbook of Neuropsychology* (eds Boller, F. & Grafman, J.) 267–299 (Elsevier, Amsterdam, 1990).
- Haxby, J. V. et al. *Proc. natn. Acad. Sci. U.S.A.* **88**, 1621–1625 (1991).
- Milner, B. *Br. med. Bull.* **27**, 272–277 (1971).
- Fiez, J. A., Petersen, S. E., Cheney, M. K. & Raichle, M. E. *Brain* **115**, 155–178 (1992).
- Grafman, J. in *Integrating Theory and Practice in Clinical Neuropsychology* (ed. Poremba, E.) 93–138 (Erlbaum, Hillsdale, New Jersey, 1989).
- Friston, K. J., Frith, C. D., Liddle, P. F. & Frackowiak, R. S. J. *Cereb. Blood Flow Metab.* **11**, 690–699 (1991).
- Talairach, J. & Tournoux, P. *Co-planar Stereotaxic Atlas of the Human Brain* (Thieme, Stuttgart, 1988).