Neuron Activity Related to Short-Term Memory

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Source: *Science*, Aug. 13, 1971, New Series, Vol. 173, No. 3997 (Aug. 13, 1971), pp. 652-654

Published by: American Association for the Advancement of Science

Stable URL: https://www.jstor.org/stable/1731738

the capillaries before being touched, and when deliberately contacted showed intensive and characteristic (*11*) cleansing. Pure regurgitated fluid, by contrast, is innocuous, and appears to function strictly as diluent. Droplets of this fluid placed on the floor of the glass arena were quickly encircled by ants and eaten. No tests were made with other predators. However, as judged from the demonstrated repellent action of quinones to other insects, spiders, and some vertebrates (*12*), there can be no doubt that *Vonones* must also be able to effect its defense in other contexts.

Two subtle additional features of this chemical weapon bear mentioning. Quinones are unstable in water, and the fact that *Vonones* makes up its solution just prior to use may reflect a functional need to do so. Moreover, the two quinones, individually, are crystalline at ambient temperatures, which would make awkward the glandular storage of either alone. In mixture, the melting point is depressed (*13*), providing the animal with a fluid, and hence appropriately dispensable, glandular content.

Vonones sayi belongs to the order Laniatores, together with over 2000 other species (*14*). Some of these were observed by one of us (T.E.) in Panama and Uruguay, and they apparently also discharge quinones, as judged by the characteristic color and odor of their effluent. In one species, quinones had been identified previously (*15*), although their defensive use against predators had not been recognized.

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References and Notes

1. T. Eisner, in *Chemical Ecology*, E. Sondheimer and J. B. Simeone, Eds. (Academic Press, New York, 1970), p. 157, and references therein.
2. The animals were collected near Denton, Denton County, Texas.
3. A. Kaestner, *Invertebrate Zoology* (Wiley, New York, 1968), vol. 2, p. 229, and references therein.
4. *Vonones*, like other arachnids, are fluid feeders. In the laboratory they drank freely from open water sources and sucked the juices from pieces of freshly killed insects.
5. Verified by autopsy, which showed the glands to contain no visible trace of brown secretion.
6. The pellets collect uncontaminated by gut fluids, since freezing does not induce regurgitation.
7. Volume calculated from microscopic measurement (with ocular micrometer) of pellet diameter.
8. This regurgitative output corresponds to about one-half the estimated capacity of the highly branched "stomach" (anterior plus posterior midgut), from which the effluent presumably stems.
9. The animals were weighed at intervals of 1 to 3 hours after milking. They regained weight at the same rate, whether offered both food (pieces of freshly killed cockroaches) and water (wet paper toweling), or water alone.
10. Filter paper impregnated with acidic solution of potassium iodide and starch.
11. T. Eisner, J. Meinwald, A. Monro, R. Ghent, *J. Insect Physiol.* **6**, 272 (1961).
12. References in T. Eisner and J. Meinwald, *Science* **153**, 1341 (1966).
13. The relative proportion of the two quinones in the secretion, determined by gas chromatographic comparison with mixtures of known concentrations of the authentic quinones, ranged from 1 : 1 to 1 : 3 in favor of the dimethyl quinone (based on four samples). Mutual depression of melting point (to below laboratory temperature; $\cong 20°$) at this range of proportions was confirmed empirically.
14. H. W. Levi, L. A. Levi, H. S. Zim, *A Guide to Spiders and Their Kin* (Golden, New York, 1968), p. 129.
15. C. Estable, M. I. Ardao, N. P. Brasil, L. F. Fieser, *J. Am. Chem. Soc.* **77**, 4942 (1955); L. F. Fieser and M. I. Ardao, *ibid.* **78**, 774 (1956).
16. Supported by PHS grant AI-02908 and PHS fellowship 5-FO2-GM-43, 424-02, and by a stipend of the Bache Fund of the National Academy of Sciences. We thank Dr. R. D. Burkett, Texas Women's University, Denton, Tex., for help in collecting *Vonones*, and Dr. W. A. Shear, Concord College, Athens, W.Va., for identifying them. Observations on Panamanian Laniatores were made at the Smithsonian Tropical Research Institute on Barro Colorado Island. We thank its research director, Dr. Michael Robinson, for help and hospitality. Paper No. 32 of our series Defense Mechanisms of Anthropods.

9 June 1971

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Abstract. *Nerve cells in the monkey's prefrontal cortex and nucleus medialis dorsalis of the thalamus show changes of firing frequency associated with the performance of a delayed response test. Most cells increase firing during the cue presentation period or at the beginning of the ensuing delay; spike discharge higher than that in intertrial periods is present in some cells throughout the delay. These changes are interpreted as suggestive evidence of a role of frontothalamic circuits in the attentive process involved in short-term memory.*

For more than a generation behavioral scientists have been investigating the deleterious effect of injury to the granular frontal cortex on short-term memory. This effect is best demonstrated in primates by the deficit resulting from ablation or functional depression of the so-called prefrontal cortex in performance of a delayed response test (*1*), whether it be the test originally devised by Hunter (*2*) or a variant thereof. A role of this part of the cerebral cortex in transient memory function has thus been operationally established, although it is not yet clear what precisely this role is.

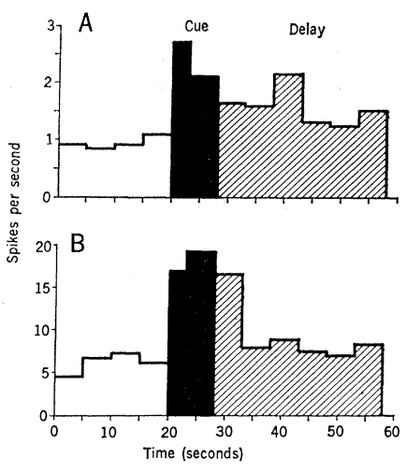

Fig. 1. Average firing of two units during five delayed response trials with 30-second delays, 20 seconds of spontaneous activity record preceding each trial. (A) Unit in prefrontal cortex; (B) unit in nucleus medialis dorsalis (MD).

We have explored in the monkey the electrical activity of nerve cells of the prefrontal cortex and of its thalamic projection nucleus, the nucleus medialis dorsalis, in the course of performance of a delayed response task. The basic hypothesis behind this work was that, if these structures are involved in some aspect of transient memory function, their neurons should manifest distinct temporal variations of spike discharge related to the events taking place in delayed response trials. Moreover, we anticipated that such variations, if present, might provide some insight into the specific role of these neurons in memory function.

Five adult rhesus monkeys were trained in the performance of a delayed response task with the use of a modified version of the Wisconsin General Test Apparatus. The experimental animal, partially restrained by a special rigid collar (*3*), sits in front of a transparent plastic window that gives him view of a well-illuminated compartment containing the test objects. Two white wooden blocks of identical form and proportions are placed on a black surface, one on the right and the other on the left, in the animal's field of vision. Directly in front of the objects, under the window, are two small doors covered with spring-loaded lids.