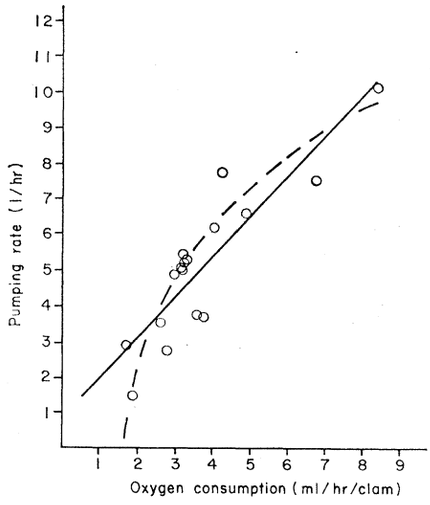

Fig. 1. Pumping rate in the hard clam *Mercenaria mercenaria* (liter/hour) graphed against oxygen consumption rate (milliliter/hour/clam). Modified from Fig. 2 of Hamwi and Haskin (*1*). Their regression line is unrealistic because it crosses the ordinate at a pumping rate of 0.84 liter/hr. The relation is obviously nonlinear as indicated by the dashed line, drawn in by inspection.

ment (Fig. 1). Oxygen consumption is directly proportional to pumping rate, but not linearly. I have drawn in a curve (dashed line) to represent the shape indicated by the data. However, two straight lines with a slope change at a pumping rate of about 5 liters per hour would also fit these data. But the unrealistic nature of the linear regression equation computed by Hamwi and Haskin is demonstrated by the fact that it predicts zero oxygen consumption when pumping rate is 0.84 liter per hour! Obviously the clam has a measurable oxygen consumption rate as pumping approaches zero, and the data indicate that this nonpumping rate of respiration is about 1.5 ml/hr per clam.

The slope of the oxygen consumption curve at minimum pumping rates indicates that the work of pumping consumes about 0.3 ml of oxygen per liter of water pumped. The slope at maximum pumping rates indicates that the work of pumping consumes about 1.5 ml of oxygen per liter of water pumped. It is not surprising that high respiration rates are correlated with high pumping rates. Pumping is work, and it is accomplished by energy supplied by respiratory processes. There is nothing in these data that suggests that pumping rate is regulated by oxygen requirement; rather, the oxygen consumption required to power the pump at maximum rate is about five times greater than it is at the minimum rate.

The data allow computation of the efficiency of the pump. In aerobic respiration the caloric value of the fuel consumed is about 0.112 calorie per micromole of oxygen consumed. Hence the pumping of a liter of water at the maximum rate burns about 7.5 calories worth of respiratory substrate. At minimum pumping rates the pump is more efficient, requiring only about 1.5 calories worth of fuel per liter pumped. Intermediate efficiencies would, of course, be obtained between these extremes.

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Reference and Note

1. A. Hamwi and H. H. Haskin, *Science* **163**, 823 (1969).
2. Supported in part by NSF grant GB-4041.

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Blockage of Olfactory Discrimination

Blockage of olfactory discrimination in salmon by puromycin, cycloheximide, and actinomycin D (*1*) does not necessarily mean that "expression of long-term olfactory memory . . . requires continuous protein or RNA synthesis, or both." While this is one possibility, numerous experiments have shown that these antimetabolites—especially puromycin—have side effects that impair neural function nonspecifically and in some cases by mechanisms unrelated to inhibition of macromolecular synthesis (*2*). The partial inhibition of protein and RNA synthesis observed by Oshima *et al.* may therefore be coincidental rather than causal. Since the effect was at least partly reversible, the only definite conclusion should be that the antimetabolites interfered with retrieval of information.

The authors' contention that their data, if sustained, "would indicate that long-term memory is a continuous metabolic process . . ." must also be questioned. While the expression of memory may have been blocked, the memory itself, or "*capacity* to behave in a way which is modified by experience" (*3*), was not destroyed. The problem may be semantic only, but in this field a clear distinction between retrieval and the storage form of information is crucial.

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References and Notes

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2. S. H. Barondes and M. E. Jarvik, *J. Neurochem.* **11**, 187 (1964); H. Cohen and S. H. Barondes, *Science* **157**, 333 (1967); N. Dahl, *J. Neurobiol.*, in pr → J. B. Flexner and L. B. Flexner, *Proc. Nat. Acad. Sci. U.S.* **57**, 1651 (1967); R. B. Roberts and L. B. Flexner, *Quart. Rev. Biophys.* **2**, 135 (1969).
3. D. Richter, in *Aspects of Learning and Memory*, D. Richter, Ed. (Heinemann, London, 1966), pp. 1–4.

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We have no argument with Irwin's statements, and, as he says, our possible differences may be only semantic. In fact it is pleasing to see that he feels "the only definite conclusion should be that the antimetabolites interfered with retrieval of information." We feel that this action of the antimetabolites may in part, at least, characterize the nature of the retrieval process. If you equate our term "expression of memory" to Irwin's "retrieval" there is no real disagreement. We agree also that the question of the storage form of nervous information is a separate one, but here again, our experiments may at least indicate something about what this storage form is *not*.

Finally, I should point out, as was done in our report, that we present these data primarily as an alternative to the current hypothesis that memory is based on residual protein or RNA templates. As an alternate hypothesis we propose that if a template exists it is probably neither of these and that expression of memory (retrieval) requires a continuous metabolic process. As Irwin points out, and as we suggested, this hypothesis is not the only one derivable from our data, but it is an important enough characterization of the memory process to deserve to be considered and tested further.

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