

10^6 to 20×10^6 dinoflagellates. The quantity and typical pale green color of pseudofeces and feces indicated that the oysters filtered the culture. Microscopic counts showed that the oysters had reduced the *G. breve* population by 90 percent after 7½ to 56 hours, at which time the molluscs were removed from the medium and homogenized. Control oysters, each exposed to 2 to 4 liters of uninoculated culture medium, opened occasionally during the experiments, but no pseudofeces and only a small amount of dark feces were observed. The assay animals, male white Leghorn chicks, did not receive food or water for 8 to 11 hours prior to the experimental period. Each of the experimental chicks was force-fed portions of a tissue homogenate of the oysters exposed to the dinoflagellates. Control chicks were each force-fed a tissue homogenate of the oysters from the uninoculated culture medium. In one experiment four additional chicks were maintained as unfed controls to determine the effect of lack of food. After the force-feeding of the chicks, they were provided water but no food for the duration of the experiments.

All eight of the experimental chicks showed a marked loss of equilibrium, and six of them died in 6 to 22 hours (Table 1). None of the control chicks showed gross toxic symptoms, such as loss of equilibrium, at the end of 24 hours, at which time they were returned to a normal diet.

Although the degree of toxicity to chicks varied from batch to batch of culture, in no instance did oysters exposed to *G. breve* fail to produce toxic symptoms in experimental animals. The age of the culture, composition of medium, and stability of toxin in the molluscs may contribute to such variability.

Another indication of the toxicity of *G. breve* was provided by the behavior of the polychaete "mudworms" (*Polychaeta* sp.), which inhabit the oyster's shell. In *G. breve* cultures the response of the "mudworms" varied from greatly reduced antennal movement to complete emergence from the shell, whereas in uninoculated medium these worms displayed normal antennal activity and remained in the shell.

Having established that oysters can ingest *G. breve* and in the process become toxic to higher animals, we suspect that the scarcity of such occurrence in nature is based on ecological barriers to contact between oysters and

G. breve. Commercially exploitable quantities of oysters usually occur in Gulf areas having average salinity levels of 25 parts per thousand or less (12). Such estuarine salinities inhibit the development of *G. breve* (11, 13). Thus salinity is probably a most important factor in preventing frequent contact between these two organisms. The scarcity of shellfish poisoning of humans in areas indigenous to *G. breve* may be attributed to this ecological pattern.

Gonyaulax monilata, the other known toxin-producing dinoflagellate from the Gulf of Mexico, remains to be investigated. Mass cultures of this organism have been established to permit controlled study of its toxic potential.

SAMMY M. RAY

Marine Laboratory, Texas
A&M University, Galveston

DAVID V. ALDRICH

Bureau of Commercial Fisheries,
Biological Laboratory, Galveston, Texas

References and Notes

1. H. Sommer, W. F. Whedon, C. A. Kofoid, R. Stohler, *Arch. Pathol.* **24**, 537 (1937); B. D. Riegel, D. W. Stanger, D. M. Wikholm, J. D. Mold, H. Sommer, *J. Biol. Chem.* **177**, 7 (1949).
2. J. C. Medcof, A. H. Leim, A. B. Needler, A. W. H. Needler, J. Gibbard, J. Naubert, *Bull. Fisheries Res. Bd. Can.* **75** (1947), p. 1; A. B. Needler, *J. Fisheries Res. Bd. Can.* **7**, 490 (1949).
3. J. M. Burke, J. Marchisotto, J. J. A. McLaughlin, L. Provasoli, *Ann. N.Y. Acad. Sci.* **90**, 837 (1960).
4. G. Gunter, F. G. Walton Smith, R. H. Williams, *Science* **105**, 256 (1947); G. Gunter, R. H. Williams, C. C. Davis, F. G. Walton Smith, *Ecol. Monographs* **18**, 309 (1948); C. C. Davis, *Botan. Gaz.* **109**, 358 (1948); W. B. Wilson and S. M. Ray, *Ecology* **37**, 388 (1956).
5. W. B. Wilson and A. Collier, *Science* **121**, 394 (1955); S. M. Ray and W. B. Wilson, *U.S. Fish Wildlife Serv. Fishery Bull.* **123**, 57, 496 (1957).
6. J. F. Howell, *Trans. Am. Microscop. Soc.* **72**, 153 (1953); C. H. Connell and J. B. Cross, *Science* **112**, 359 (1950).
7. J. E. Gates and W. B. Wilson, *Limnol. Oceanog.* **5**, 171 (1960).
8. B. Eldred, K. Steidinger, J. Williams, in *A Collection of Data in Reference to Red Tide Outbreaks during 1963* (Marine Laboratory, Florida Board Conservation, St. Petersburg, 1964), p. 23.
9. E. F. McFarren, H. Tanabe, F. J. Silva, W. B. Wilson, J. E. Campbell, K. H. Lewis, *Toxicon*, in press.
10. A. Dragovich and J. A. Kelly, Jr., in *A Collection of Data in Reference to Red Tide Outbreaks during 1963* (Marine Laboratory, Florida Board Conservation, St. Petersburg, 1964), p. 4.
11. D. V. Aldrich and W. B. Wilson, *Biol. Bull.* **119**, 57 (1960).
12. P. A. Butler, in *Gulf of Mexico Its Origin, Waters, and Marine Life*, P. S. Galtsoff, Ed., *U.S. Fish Wildlife Serv. Fishery Bull.* **89**, 55, 479 (1954).
13. J. H. Finucane and A. Dragovich, *U.S. Fish Wildlife Serv. Spec. Sci. Rept. Fisheries* **289** (1959).
14. Supported by PHS grant EF-00614-01 and by Organized Research Fund, Texas A&M University. We thank W. B. Wilson for technical advice regarding the culturing of *Gymnodinium breve* and Miss A. M. Sievers for technical assistance.

12 March 1965

Two-Stage Paired-Associate Learning and Eye Movements

Abstract. Eye movements of 20 male students were photographed continuously throughout the course of their learning verbal paired-associates. As learning progressed, proportionately less and less time was spent scanning the response when the stimulus and response were presented together. These findings are interpreted as supporting a two-stage theory of verbal learning.

In experiments on verbal paired-associate learning, subjects are required to associate pairs of items, usually nonsense syllables, such that the presence of the first or stimulus member comes to elicit the second or response member. A number of investigators (1) regard the learning of such lists as a two-stage process, subjects consolidating the responses during the first or "response-learning" phase and then connecting them to the appropriate stimuli during the second or "hook-up" stage. We evaluated this notion by examining the eye movements of subjects throughout the course of their learning paired-associates, concentrating on the proportion of time each subject spent fixating the stimulus and the response when the two were presented together. If subjects scanned the response out of proportion to the stimulus during the early learning trials, the two-stage concept would be supported.

Twenty male students of introductory psychology were used as subjects. As each entered the laboratory he was placed in a dental chair, the various attachments of which facilitated the recording of eye movements, and was given standard instructions for paired-associate learning. We told him that he would be required to learn a list consisting of seven pairs of nonsense syllables. Each syllable had a Nobel (2) m' value within the range 1.80 to 1.93. For each syllable-pair, we exposed the stimulus alone and then with the response by projecting slides onto a green-surfaced chalkboard 1.37 m in front of the subject. We told him that when the stimulus was presented by itself he had 2 seconds in which to anticipate the response and when the two appeared together, the stimulus on the left and the response on the right, he would discover whether he was correct or incorrect. The list was given in each of four different random orders

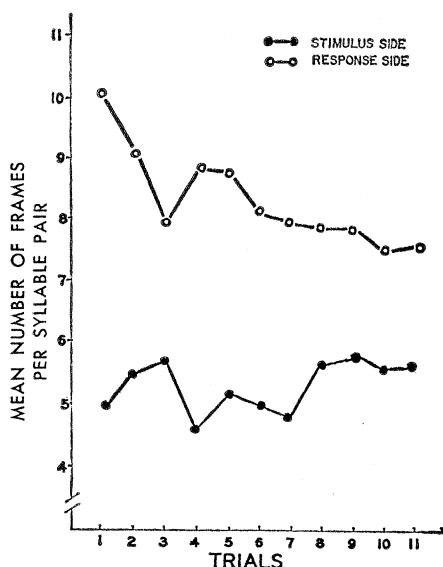


Fig. 1. Mean number of frames of stimulus and response as a function of trials.

(trials) to prevent serial learning, and we inserted two blank slides at the end of each trial to provide a 4-second intertrial interval. The subject was given a 1-minute rest at the end of every four trials and the session was terminated after 24 trials, or before that if he successfully anticipated the seven responses in any of the four orders.

We recorded eye movements continuously throughout the duration of the task by means of an eye-marker camera (3), mounted on the head, which consisted of a 2- by 8-mm motion picture unit and a periscope that transmitted a spot of light reflected from the cornea to a moving film. The developed film shows the paired-associate slides and, superimposed upon each, a bright circular spot indicating the position of actual fixation. We analyzed the data frame by frame, by examining the stimulus-response slides through a film viewer. This method of analysis was highly dependable, the between and within experimenter-reliability coefficients being 0.98 for a film of 24 trials, selected at random.

Sixteen of the 20 subjects reached the criterion of an errorless trial, the fastest doing so on the 11th trial. We have summarized the main findings in Fig. 1. The first 11 trials for all subjects are shown along the abscissa, while the ordinate represents the average number of frames per syllable-pair for those slides where the stimulus and response appeared together. The open

circles represent response frames, the closed circles stimulus frames. For any given trial, total frames of stimulus and response may be calculated by adding the ordinate values for the open and closed circles. The difference between this value and 21 represents frames involving fixations of the central portion of the display. The two functions shown in Fig. 1 are not perfect mirror images of one another and this is reflected by a -0.43 correlation between stimulus and response frames.

We examined the findings shown in Fig. 1 by means of analysis-of-variance techniques and discovered that the two trend lines depart reliably from being parallel ($p < .001$), with time on stimulus remaining constant over trials and time on response becoming systematically shorter as learning progresses. This last trend has a chance expectancy of less than one in one thousand, an orthogonal polynomial comparison revealing no dependable nonlinear components. We obtained the same results by examining time on stimulus and response as a function of the first three of the four quarters of learning for those 16 subjects who reached the errorless-trial criterion. (We omitted the data for the fourth quarter because of their unreliability.) All 16 subjects showed less time on the response during the third quarter than during the first. Again, time on stimulus remained essentially invariant throughout the session.

In view of the fact that each subject saw the stimulus twice as often as the response, it is not surprising that the latter was scanned out of proportion to the former throughout the duration of the task. Nor were we surprised to discover less total time on stimulus and response during the latter stages of learning. This resulted from a tendency to fixate the central portion of the display, or even to look away, once a syllable pair had been learned. The phenomenon of most interest, however, that of the systematically decreasing ratio of response- to stimulus-time with trials, is clearly consistent with the two-stage hypothesis. This phenomenon reflects the transition from the response consolidation to the stimulus hook-up phase.

We also analyzed scanning behavior before and after the learning of each of the seven pairs and found what could be interpreted as additional support for

the two-stage theory. Although there were no differences in time on the stimulus, all 20 subjects showed less time on the response after the pairs had been learned than before. This difference on the response side and lack of it on the stimulus side of the display is presumably due to a disproportionate amount of time on the response during stage one, even though the data presented before learning reflect both stages.

We were unable to reveal any reliable differences in scanning behavior between slow and fast learners, nor were we able to demonstrate any systematic changes in patterns of viewing the stimulus-response slides as learning progressed. Most subjects looked right-left-right and maintained this pattern throughout the duration of the session.

P. D. MCCORMACK

E. J. HALTRECHT

Department of Psychology,
Carleton University,
Ottawa, Canada

References and Notes

1. G. Mandler, *Psychol. Rev.* **61**, 235 (1954); L. Postman, in *Verbal Learning and Verbal Behaviour*, C. N. Cofer, Ed. (McGraw-Hill, New York, 1961), pp. 152-179; B. J. Underwood and R. W. Schulz, *Meaningfulness and Verbal Learning* (Lippincott, Chicago, 1960), pp. 92-94.
2. C. E. Noble, *Psychol. Rep.* **8**, 487 (1961).
3. N. H. Mackworth and E. L. Thomas, *J. Opt. Soc. Amer.* **52**, 713 (1962).
4. This research was supported by a grant-in-aid from the Associate Committee on Experimental Psychology of the National Research Council of Canada (grant APA-78) and by the Carleton University Arts Research and Publication Fund.

11 February 1965

Pupillary Response of the Screech Owl, *Otus asio*

Abstract. *The latent period of constriction in the owl is only half that in the human, and the latent period of dilatation is about equal to that in the human. Similarly, the rise time of constriction in the owl is much faster than that in the human. The owl system has the characteristics of a low-band-pass filter. The owl's frequency response is over an octave lower than that of the human, but its phase lags are shorter.*

Linear and nonlinear servomechanism theory has been used to describe quantitatively the dynamic characteristics of the human pupillary response to a small-signal visible light input (1).