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The Cognitive Animal

Empirical and Theoretical Perspectives on Animal Cognition

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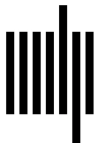
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The pinnipeds, or seals, sea lions, and walruses, are descendants of terrestrial carnivores. In contrast to their fully aquatic counterparts, the dolphins, they are shorter lived, have less complex social organization, and have a less encephalized brain. Despite these facts, some pinniped species display obviously intelligent behavior, which can be seen in the ease of their trainability in oceanaria settings and in their ability to trick unlucky fishermen out of their catch. The quick wits and adaptability of one species in particular, the California sea lion (*Zalophus californianus*), make it an ideal subject for our laboratory studies of problem solving and memory.

Language Learning in the Sea Lion

Historically, a top-down approach has been used to study cognition in a select group of mammals, including the great apes and bottlenosed dolphins. This approach emphasized the search for rudiments of language in nonhuman animals. Our own early work on sea lion cognition, namely, teaching them to comprehend an artificial gestural sign language (Schusterman and Gisiner 1988, 1989, 1997; Schusterman and Krieger 1984, 1986), was inspired by the apparent success of similar research with bottlenosed dolphins (see Herman et al. 1984). Throughout much of the 1980s, we focused our efforts on teaching three sea lions to relate particular gestural signals to objects (such as bats, balls, and rings), modifiers (large, small, black, and white), and actions (such as fetch, tail touch, and flipper touch). These signals could be combined in over 7000 different combinations, each instructing the animal to carry out a specific behavioral sequence. For example, in what was termed a “single object” instruction, the presentation of four signs such as *small white ball flipper-touch* would usually result in the sea lion touching the small white ball with its flipper, while ignoring

the irrelevant objects in the pool (see figure 28.1). More complicated instructional sequences required the sea lion to press one of two paddles to indicate whether an object was present or absent. The most complicated instructions required the sea lion to select one object in the tank and bring it to another object. These “relational” sequences could include up to seven signs; for example, the gestural sequence *large white cone, black small ball fetch* instructed the sea lion to bring the black small ball to the large white cone. Our sea lions were eventually able to respond appropriately to familiar as well as novel combinations of signs with a great deal of accuracy, as shown in figure 28.2, which describes the performance of our most experienced sea lion, Rocky.

Our results with the sea lions in the language-learning task gave us insight into several aspects of their cognitive abilities. Positive results with animals that were smaller brained, shorter lived, and less social than apes and dolphins led us to speculate that we were dealing with general learning processes rather than specialized cognitive abilities such as language. Instead of comprehending the instructional sequences within a linguistic framework, we believed that our sea lions, and perhaps other animals trained on similar tasks, were learning specific problem-solving rules via the associative mechanisms we describe later.

The artificial language tasks also led us to make predictions about how sea lions represented and remembered critical information. For example, our sea lion Rocky exhibited a stereotyped search response following her observation of the gestural cue denoting an object. As soon as she was given the cue, Rocky would turn her head to the left and slowly scan the pool until she located the correct object, at which point she would return to station to wait for the action signal to be given (see figure 28.1). Her purposeful search for the specified object suggested that

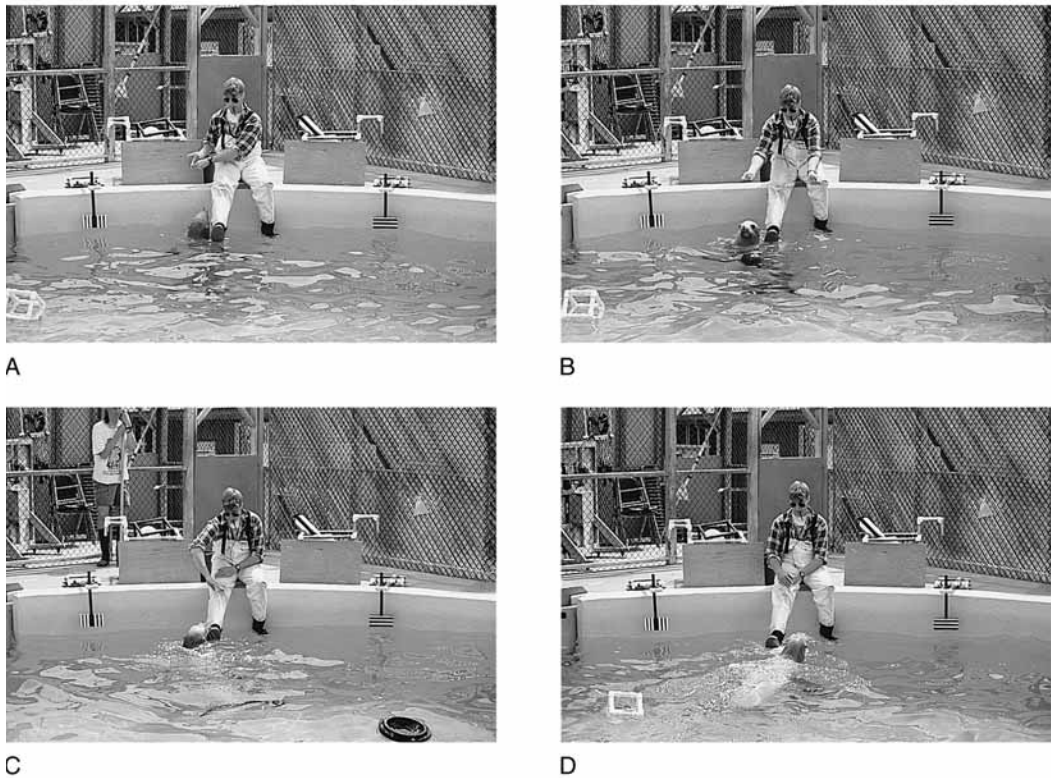


Figure 28.1

An instructional sequence given to sea lion Rocky by a trainer in the context of the language experiment: the gestural cue for the modifier WHITE (A), followed by the cue for the object DISK (B), and then the cue for the action FETCH (C). Rocky responds to the modifier cue with a slight head turn (A), but responds to the object cue by turning her head until she finds and points at the white disk (B). After finding the disk, she returns to her stationing position at the trainer's foot and receives the fetch sign (C). When the trainer's foot drops, Rocky carries out the instructional sequence WHITE DISK FETCH by bringing the white disk to the trainer (D).

she was coding the object signal prospectively; that is, she was translating the gestural cue into a representation, or search image, of the target object. This search image hypothesis is further supported by Rocky's performance on trials based on the presence or absence of an object. On such trials, her search time was significantly longer when the signed object was absent than when it was present (2.4 ± 0.8 seconds versus 1.6 ± 0.6 seconds; $t = 5.6$, $df = 97$, $p < .01$).

Rocky's search behavior on different types of instructional sequences also led us to other observations about her memory. For example, while scanning the pool, Rocky seemed to hold onto the search image of the object for a maximum of about 10 seconds. If she failed to locate the target object within that time period, she often refused to respond or simply "defaulted" to responding to any nearby object. This observation led us to hypothesize that California sea

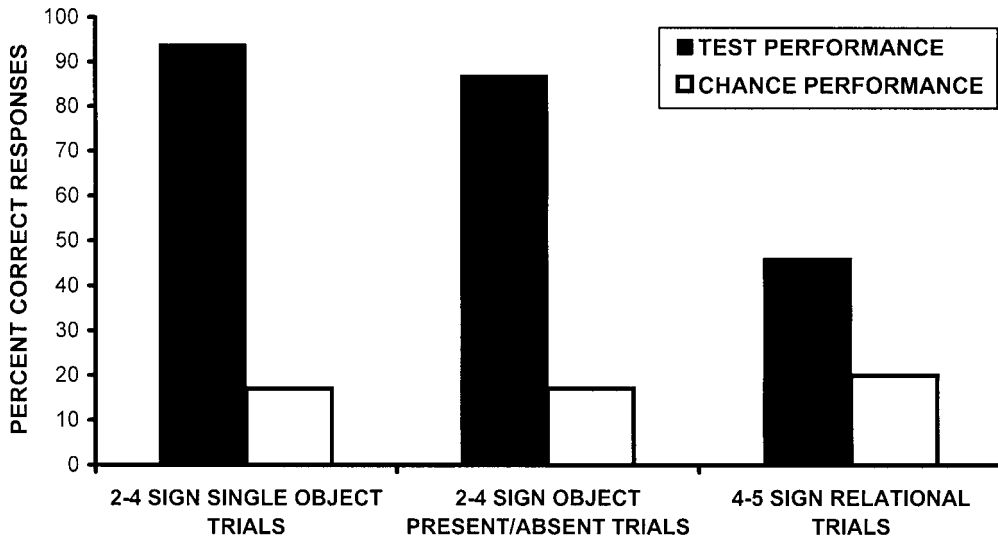


Figure 28.2

Sea lion Rocky's performance accuracy on three instructional types: single object ($n = 1087$ trials), object present or absent ($n = 99$ trials), and relational ($n = 35$ trials). The present or absent results are a random sample drawn from Rocky's data obtained in March 1988 and presented here for the first time. The single object and relational trials are taken from Schusterman and Gisiner (1988). The black bars show the percentage of correct responses to each instructional type and the white bars present performance expected by chance (all χ^2 's for these data indicated that performance was significantly better than chance, $p < 0.01$. [See Schusterman and Gisiner (1988) for the calculation of chance probabilities.]

lions had a limited short-term memory. In addition, on trials involving two different objects, Rocky would usually remember the most recently signed object while sometimes forgetting the earlier signed object (Schusterman et al. 1993a). This type of performance reflects attempts at remembering earlier material while being distracted by more recent material. It is typical of what is termed retroactive interference, which occurs when the encoding of new information disrupts the retention of previously coded information.

Collectively, these findings generated more questions than answers. How did the sea lions relate gestural signals to the objects they represented? Did the sea lions learn new signals in a manner analogous to the way that children learn

new words? What was the relationship between the type of language learning demonstrated by the sea lions and their more general abilities to form abstract concepts? What were the limits of their short- and long-term memory? Finally, how did performance on psychological tests given in a laboratory setting relate to natural social and ecological problem solving?

From Language to Logic

To answer these questions regarding basic learning and memory processes, we changed our approach from top-down, beginning with complex languagelike performances and attempting to identify the components and variables influencing behavioral responses, to bottom-up, in which

we could look at the formulation of problem-solving rules under more simplified and controlled conditions. This change was motivated by the idea that the gestures used in the language experiment to designate particular objects served as conditional cues that were arbitrarily related to each object by positive reinforcement training. We believed that the performance of our sea lions in the language experiment depended on their acquisition of straightforward, albeit complex, conditional discriminations or *if . . . then* rules, rather than on linguistic processes. For example, a sea lion could be trained to follow the rule “*If the gesture for disk is presented . . . then respond to the object disk.*” Although the behavior of the sea lion seems to indicate comprehension of language, this type of rule learning is different from the symbolic nature of human language, in which a symbol becomes equivalent to its referent.

Conditional Discrimination Learning

In order to analyze rule learning in our sea lions, we abandoned our artificial language project and began training two sea lions in a procedure known as arbitrary matching-to-sample (MTS). This procedure allowed us to examine the relationship between potential symbols and their referents. The MTS task requires a subject to respond to one of two or more choice, or comparative, stimuli in the presence of a particular conditional cue, or sample stimulus (Carter and Werner 1978). A sample stimulus and its paired associate are arbitrarily related in much the same way that a gestural cue in the language project is related to an object. For example, through positive reinforcement training, a sea lion can learn to respond to a pattern shaped in the form of a crown, given the presence of a sample stimulus shaped in the form of a propeller, i.e., “*if propeller . . . then crown*” (see figure 28.3).

The sea lions’ performance in the MTS task was similar to their performance in the language project. Despite the differences in configuration

between the two tasks, the observed patterns of errors (including object and position biases) were quite similar. This was a strong indication that the sea lions were learning comparable *if . . . then* rules to solve the two types of problems.

Learning by Exclusion

The conditional discrimination problems just described were established in two different procedures, but shared an important training characteristic. In MTS and in the artificial language task, the first two conditional discriminations were trained simultaneously by trial and error; as expected, each subject made a significant number of mistakes during the acquisition of the first paired associates. The development of such specific rules through training generally requires a subject to make some errors in order to sort out the contingencies that predict reinforcement. However, following initial training in the language task, we found that our sea lions could learn associations between new gestures and new objects virtually without error.

When a novel gestural cue was produced in the presence of both a novel object and a familiar object (that is, one already associated with a different gestural cue), the sea lion immediately related the novel signal to the novel object and excluded the familiar object as a probable choice (Schusterman and Gisiner 1997). Thus, when a novel gestural cue was incorporated into the sequence, Rocky responded immediately to the only novel object in the pool. We obtained the same results in MTS—the sea lions excluded the familiar comparison, which had already been associated with a familiar sample, and immediately related the novel sample to the novel comparison (Kastak and Schusterman 1992; Schusterman et al. 1993b).

The same phenomenon has been reported in language learning experiments with both dolphins and great apes. Indeed, developmental psycholinguists have documented a similar phenomenon in word learning by children who

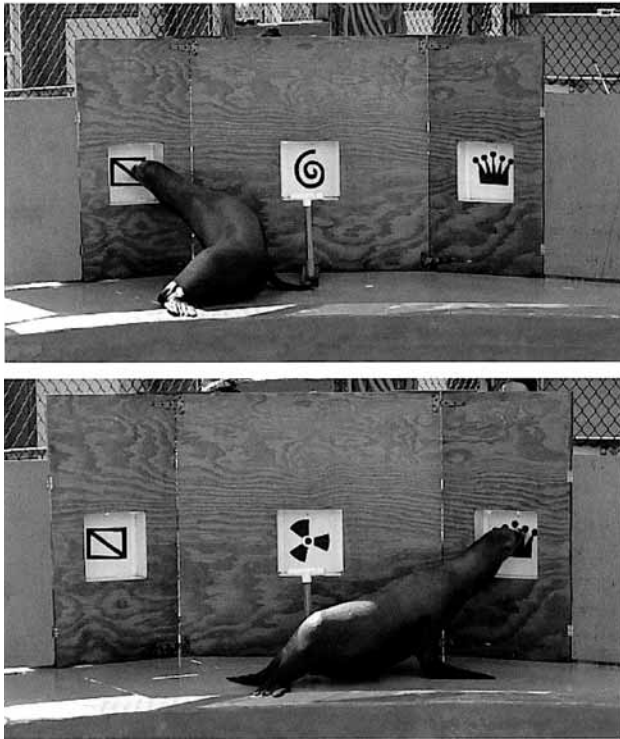


Figure 28.3

Examples of Rocky solving conditional discrimination, or *if . . . then*, problems in the matching-to-sample procedure. The sample stimulus, or conditional cue, appears in the center of the apparatus, and comparison, or choice, stimuli appear on either side of the sample. Following an observation interval during which time all three stimuli are visible, Rocky is released from her stationing position in front of the sample stimulus to touch one of the choice stimuli. Correct stimulus matches are rewarded with fish reinforcement. In the upper panel, selection of the rectangle is contingent upon presentation of the spiral, i.e., “*if spiral . . . then rectangle*”; in the lower panel, selection of the crown is contingent upon presentation of the propeller, i.e., “*if propeller . . . then crown*.”

relate new words to new objects in their environment without error; this process has been described by various terms, such as *psycholinguistic inference*, *emergent matching*, *fast mapping*, and *mutual exclusivity* (Wilkinson et al. 1998). Any individual who uses an exclusion rule to deduce that two items must be related can eventually learn the more direct association between the two items. Once the direct association has been firmly established, the strategy of

excluding the familiar item will no longer be necessary. Thus, the use of an exclusion rule minimizes frustration during the learning process by eliminating errors, and this is true whether the subjects are sea lions, dolphins, chimpanzees, or children. In summary then, we can see that part of the performance of sea lions in a languagelike task can be attributed to relatively simple forms of learning, such as specific *if . . . then* rules and a more general exclusion rule.

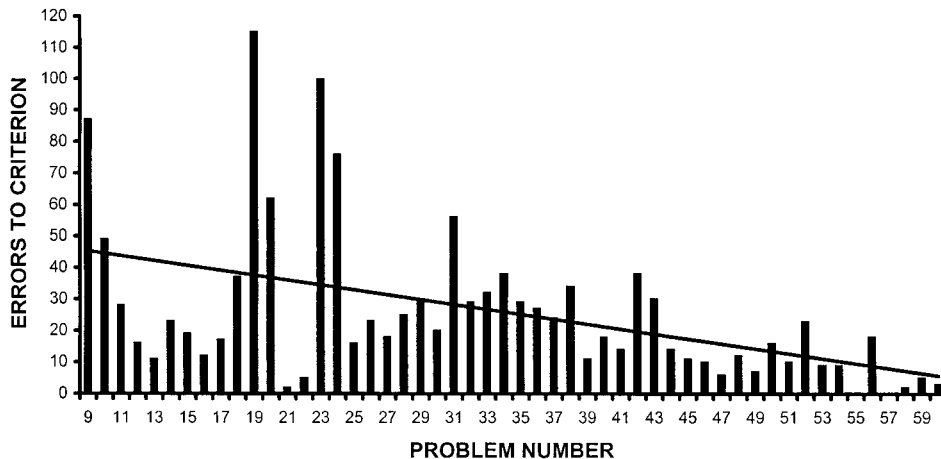


Figure 28.4

Performance for sea lion Rio on 52 successive conditional discrimination problems. The number of errors Rio made prior to reaching criterial levels of performance (90 + percent correct responses) declined significantly as she learned more and more problems of the same type ($R^2 = 0.23$, $p < 0.01$). These data for the learning set in MTS are presented here for the first time.

Learning to Learn

With repeated practice with a particular type of problem, an individual can often solve subsequent problems of the same type more rapidly (Harlow 1949). Thus, animals not only learn how to respond appropriately to individual problems but can also learn about the more general nature of the problems and how to solve them efficiently. We have observed this “learning set” phenomenon in our sea lions in a wide variety of situations, including language learning and MTS (see also Schusterman 1968). For example, using MTS, we trained our sea lion Rio to solve 60 different conditional discriminations. The problems were set up in such a way that Rio could solve the first 8 of these problems by using an exclusion rule, but thereafter had to solve the remaining 52 problems by learning specific *if . . . then* rules for each of two paired associates. Rio’s performance on these problems can be seen in figure 28.4, which shows that the number of

errors required for her to learn each successive problem gradually decreased. This pattern indicates that Rio formed a learning set, a general strategy for solving similar types of problems.

Equivalence Relations

Our language studies with the sea lions brought into question the symbolic nature of the gestural cues used to denote the modifiers, objects, and actions in an instructional sequence. We found that the responses of our sea lions to novel instructional sequences depended on the order in which the gestural cues were presented. The sea lions were trained to expect cues in the following order: modifier(s)-object(s)-action. A novel gestural cue placed in the modifier, object, or action position of a sequence would invariably result in the appropriate type of response. For example, after Rocky was trained by shaping procedures to porpoise over an object floating in her pool, and the behavior was placed under the control of

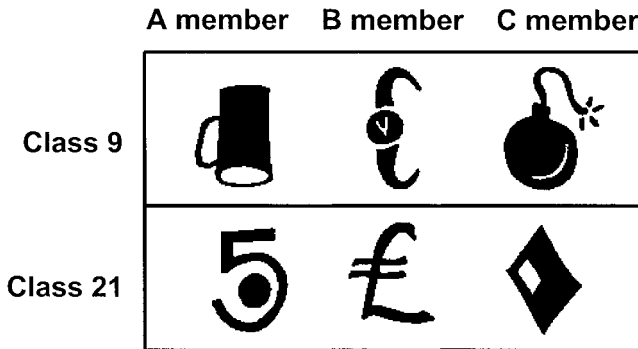


Figure 28.5

The A, B, and C members of two classes (9 and 21) that were part of the 30 potential 3-member classes used with sea lion Rio. Following MTS training of the relations *if A ... then B* and *if B ... then C* for each class, Rio was tested for the ability to form symmetrical (*if B ... then A; if C ... then B*), transitive (*if A ... then C*), and equivalence (*if C ... then A*) relations (see Schusterman and Kastak 1993, 1998).

a gestural cue, she was able to perform perfectly the first time she was given the sign sequences *ball over* or *white cube over*. However, if the object and action cues in a sequence were transposed, Rocky would frequently balk, indicating that she did not comprehend anomalous sequences. Any modifier, object, or action could be substituted for another in an instructional sequence, but they could not be substituted between signal types. These observations suggested that Rocky was organizing the gestural cues into classes based on the type, or function, of the signal. Because the type of signal is specifically related to its position in the sequence, such categorization is evidence of syntactic comprehension (Gisiner and Schusterman 1992).

In addition to such syntactic meaning, conceptual behavior can also be demonstrated in the context of symbolic meaning. The most commonly used paradigm in studying the symbolic nature of human words is called “stimulus equivalence,” which is studied in the context of the MTS procedure (see Sidman 1994, 2000). Following the training of the conditional discriminations *if A ... then B* and *if B ... then C*,

stimulus equivalence is shown by the emergence of novel reflexive, or identity, relationships (*if A ... then A, if B ... then B, if C ... then C*), symmetrical relationships (*if B ... then A* and *if C ... then B*), and transitive relationships (*if A ... then C*). A complete equivalence relation combines symmetrical and transitive properties, and would be demonstrated if an individual could spontaneously relate *C* to *A* following training of the original rules *if A ... then B* and *if B ... then C*. In the context of word learning, the stimuli *A*, *B*, and *C* might refer to an object, its verbal label, and its written label. To examine the potential for symbolic meaning in our sea lions, we tested one of our animals for the ability to form equivalence relations using MTS and stimuli such as those shown in figure 28.5.

Our general strategy for documenting equivalence classification was to teach Rio to solve problems of a given type by direct reinforcement training and then test her to see if she could solve novel problems of the same sort. For example, after being trained with 60 identity problems in the form of conditional discriminations (i.e., *if A ... then A*), Rio was tested with 30 unfamiliar

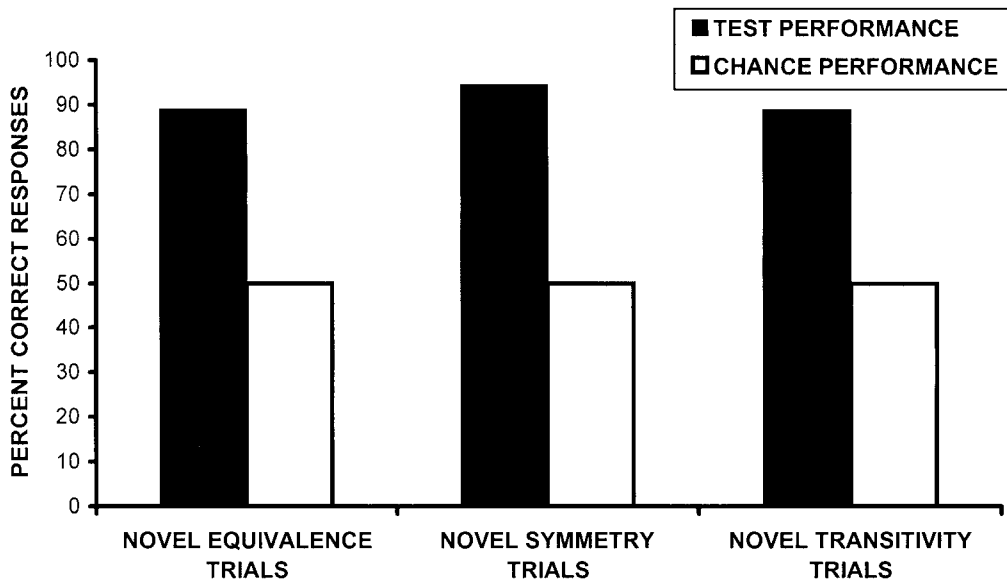


Figure 28.6

Sea lion Rio's trial one performance on tests of equivalence (*if C ... then A*), symmetry (*if B ... then A*, and *if C then A*), and transitivity (*if A ... then C*) for 18 potential classes following exemplar training with 12 other potential classes. Performance on all conditions is significantly better than expected by chance (Fisher's exact tests, $p < 0.01$; $n = 18$ for equivalence trials, $n = 36$ for symmetry trials, and $n = 18$ for transitivity trials).

stimuli; she correctly related identical pairs of objects (i.e., *if novel stimulus X ... then novel stimulus X*, *if Y ... then Y*, *if Z ... then Z*, etc.) 80 percent of the time even though she had never seen the objects before (Kastak and Schusterman 1994). Following these tests, Rio was taught conditional discriminations with 30 potential equivalence classes, each consisting of three different shapes (see figure 28.5). For each of the 30 classes, the conditional relations *if A ... then B* and *if B ... then C* were directly trained. Subsequently, 12 of the 30 classes were used to train the relational rules of symmetry and transitivity in order to give Rio experience solving these types of problems. Finally, the remaining 18 classes were presented to Rio in new configurations to determine if equivalence relations would emerge without training. The results

shown in figure 28.6 demonstrate Rio's remarkable ability to reorganize trained stimulus relations into emergent combinations based on the properties of symmetry, transitivity, and equivalence (Schusterman and Kastak 1993).

Additional experiments have extended these results on equivalence relations to show such classification occurring in other discrimination learning contexts (Schusterman and Kastak 1998), and class membership expanding to include specific reinforcers such as different types of fish (Reichmuth Kastak et al. 2001). This conceptual reorganization of information allows an animal to connect different objects, events, and individuals in structured categories on the basis of common elements or shared functions. While humans use linguistic codes to facilitate such abstract problem solving, these studies show

us that some nonhuman animals that lack language are nonetheless capable of logically organizing their perceptual worlds.

Remembrance of Things Past

Information, once organized into relationships, rules, or categories, must be remembered over time in order to be useful to an animal. Thus, processes related to the coding, storage, retention, and retrieval of information are fundamental to studies of animal cognition. In the language studies, the sea lions seemed to retain representations for very short time intervals, and distracting events appeared to disrupt these representations. To more systematically investigate aspects of short-term, or working, memory in our sea lions, we trained two of them to perform a variant of the MTS task, called “delayed matching-to-sample.”

After the sea lions learned to relate sample stimuli to correct comparison stimuli in the standard procedure (see figure 28.3), memory trials were conducted in which the sample stimulus was removed prior to the presentation of the comparison stimuli. The delay between the removal of the sample and the presentation of the comparisons was varied in order to determine the time interval over which the encoded sample could be retained. We found that our sea lions continued to accurately solve the problems for as long as we could reasonably ask them to wait for the comparison stimuli to be shown. Delay periods were extended to 2 minutes for our older and more patient sea lion Rocky, and 45 seconds for our younger and more active sea lion, Rio. The performance of both animals across all delay intervals was consistently at about 90 percent correct responses (Schusterman et al. 1991).

We did not observe a gradual decline in performance with increasing delay intervals, as might be expected if the information encoded from the sample gradually faded from working memory. However, we did note that if irrelevant

stimulus material was presented during the delay interval, performance on the memory trials was completely disrupted. This finding is consistent with our observations in the language experiment, showing that retroactive interference leads to forgetting by disrupting the retention of encoded information in short-term memory.

In contrast to short-term memory, which is easily disrupted, long-term memory for individuals, locations, and tasks appears to be relatively stable for periods ranging up to several years. Recently, we attempted to quantify a sea lion’s ability to remember relationships that it has not experienced for a long period of time. We tested our sea lion Rio to determine if she could remember two categories containing ten stimulus members each. Although Rio had not been exposed to the stimuli or the procedure for 12 months, she correctly related stimuli belonging to the same category without a single error on her memory test. Rio’s excellent memory for these and other previously learned categories suggests that meaningful or conceptual material may persist in memory for very long periods of time.

Solving Problems in Nature

Our laboratory experiments with California sea lions show how their brain is used to transform perception into meaning and action. We hypothesize that sea lions use the same processes of classification and memory in attempting to solve problems in nature (Schusterman et al. 2000).

For instance, sea lions are capable of recognizing each other as individuals. If a sea lion can form equivalence classes corresponding to labels such as conspecifics, neighbors, allies, and kin, it can more efficiently solve problems by dealing with categories of individuals that may be treated in a similar manner; responses appropriate to one member of a class may, depending on the context, be appropriate for other members of a class.

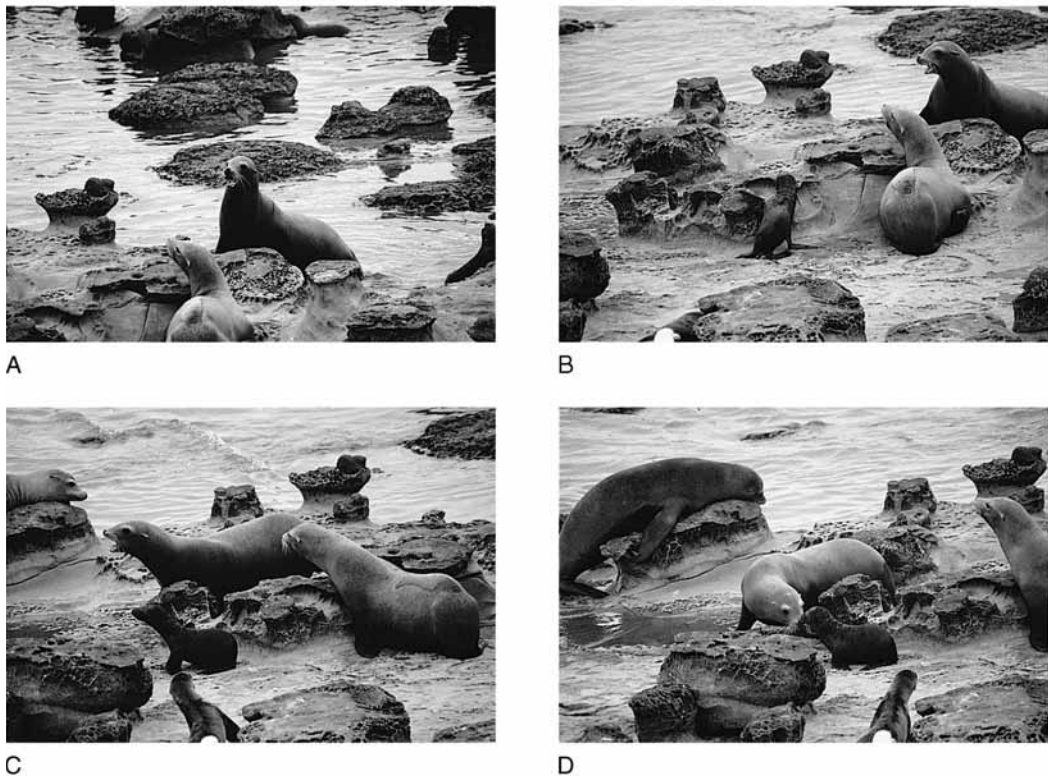


Figure 28.7

A California sea lion mother–pup reunion. (A) Upon returning to the rookery, the mother emits her signature pup attraction call. (B) The pup responds to the call of its mother, and the pair exchange signature vocalizations and move closer to one another. (C) While continuing to call to her pup, the mother leads the pup around a physical barrier. (D) Mother and pup touch noses and confirm auditory recognition by olfactory, tactile, and visual cues.

The complex behaviors leading to individual and kin recognition appear to be fairly well developed in California sea lions. Immediately following birth, both mother and pup acquire sensory information and form meaningful representations of one another based on hearing, vision, olfaction, and touch. This imprinting process results in mutual recognition, which is critical to maintaining contact over and beyond the lactation period. As a result, when females return to the rookery after a foraging bout that may last several days, they are able to locate

and reunite with their dependent pups. These reunions depend on the exchange of signature vocalizations at long range, followed by the confirmation of identity at short range via smell, sight, and touch, as shown in figure 28.7. Furthermore, sea lions born to the same mother in different years may learn to recognize one another through their mutual connection with their mother.

We believe that individual and kin recognition are closely tied to the process of equivalence class formation. For example, a pup's recogni-

tion of its mother may depend on the association of many sensory cues with the common reinforcing elements of warmth, contact, and nourishment, while a female's recognition of her sisters may depend on their mutual association with their mother (Schusterman et al. 1992).

There is accumulating evidence that a territorial male sea lion or fur seal recognizes the vocal displays of neighboring rivals. Over several breeding seasons, a male behaves as if it has categorized its competitors into familiar and novel groups. In a seminal investigation on the male territorial and reproductive behavior of Steller sea lions (*Eumetopias jubatus*), Gisiner (1985) found that the most reproductively successful males were those that had at least three seasons of experience maintaining nearly the same territorial site. These experienced males probably grouped neighboring males into classes of "familiar" and "novel" and became successful by not expending time and energy on aggression against familiar rivals, and instead fighting newcomers vigorously and successfully.

Furthermore, female Steller sea lions may also group males into two classes. Gisiner observed that a female was most likely to approach sites occupied by males with long territorial histories, while avoiding sites occupied by males in their first or second year on a territory. The behavior of the male Steller sea lions observed by Gisiner most likely depends on the classification of individuals into categories and a long-term memory for territorial sites, individuals and their signature vocalizations, and outcomes of previous aggressive contests. Female Steller sea lions probably depend on similar processes in choosing their mates.

There are many other examples of cognition gleaned from observations of wild sea lions that may apply to ecological as well as social problem solving. Our research in the laboratory has given us insight into the cognitive processes used by wild animals in such problem solving, and our results continue to raise more questions about

their cognitive characteristics. As we get closer and closer to describing "the cognitive sea lion," we have been forced by our data to take a general process approach. We believe that many of the seemingly complex behavioral phenomena that we have elicited in the laboratory can be considered in the context of straightforward associative principles, which nevertheless give rise to a great deal of behavioral complexity. These same associative processes seem to be at work in a variety of natural contexts and are most likely common to many different animal species.

Acknowledgments

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