was offered as proof that ADP from red cells was involved in platelet reactivity (*13*). However, these agents also directly affect platelet function; thus it is difficult to conclude that the prolonged bleeding is due to effects induced solely by red cells. Conversely, other investigators (*14*) demonstrated that the quantities of adenosine triphosphate and ADP found in blood subjected to platelet retention in glass bead columns are more consistent with amounts released by platelets (1.5:1) than red cells (10:1) and are not correlated with the amounts of hemoglobin released by red cells.

It has also been suggested that red cells deposit material on blood vessel surfaces that may affect the platelet interaction; the quantity and type of protein deposition on prosthetic surfaces have been altered by adding red cells to plasma (*15*). The nature of the protein layer is believed to affect subsequent platelet interaction with surfaces.

Although the nature of the effect of red cells at high shear rates on the formation of platelet thrombi is not entirely clear, it is apparent that red cells may play a greater role than generally suspected. Our results indicate that at low shear rates (comparable to flow in large veins) or low hematocrit values, the effect is predominantly one in which the red cells physically enhance the arrival rate of platelets (and presumably proteins) to the surface. A low arrival rate may explain why platelet thrombi form less frequently in the venous circulation and why the prolonged bleeding time in some anemias may be corrected by transfusion of red cells (*1*). At high shear rates (comparable to flow in the microvasculature) and high hematocrit values, an additional red cell mechanism results in increased thrombus formation. In polycythemia, thrombotic and bleeding episodes are a frequent complication and have been attributed in part to the reduced vascular blood flow associated with increased blood viscosity at high hematocrit values (*16*). The results of the present investigation suggest an alternative explanation for the development of platelet thrombi at high hematocrit. An extension of our results to clinical situations is that, in general, patients suffering from recurrent thrombotic episodes of a platelet origin may benefit from a reduced hematocrit and that, conversely, addition of red cells may be prophylactic in those with hemostatic defects.

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Symbolic Communication Between Two Pigeons *(Columba livia domestica)*

Abstract. *Through the use of learned symbols, a pigeon accurately communicated information about hidden colors to another pigeon. Each verbal exchange was initiated with a spontaneous request for information. The two pigeons engaged in a sustained and natural conversation without human intervention.*

In a recent report, Savage-Rumbaugh *et al.* (*1*) described the first successful demonstration of symbolic communication between two nonhuman primates. They showed that chimpanzees' nonverbal communication ability could be enhanced through learning. Specifically, the chimpanzees exchanged information about food through the use of geometric symbols. They were first taught to name a number of foods by pressing buttons on which corresponding symbols were marked. Then they were taught to request hidden food by using its symbolic name. Finally, in a test of how well information about a given food could be transmitted from one chimpanzee to the other, one chimpanzee watched while some food was hidden and, in the presence of the second chimpanzee, was asked by the experimenter to indicate the symbolic name for that food. If the second chimpanzee then correctly asked for that food by using its symbolic name, both subjects were rewarded with the food. Also briefly described was a situation in which the chimpanzees spontaneously used symbols to request food from each other. Evidently, communication through the use of symbols is not an activity that is necessarily unique to man. The question naturally arises as to whether it is unique to primates.

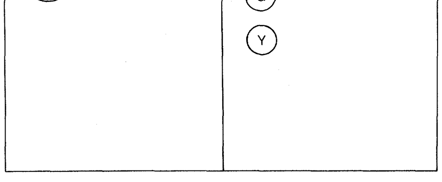

Fig. 1. Adjoining keyboards for the two pigeons. Jack's is on the left and Jill's is on the right. Jack needs information about the color recessed 5 cm behind the curtain in the upper right-hand corner of Jill's keyboard. The *R*, *G*, and *Y* on Jill's keyboard are black on white. The three keys below the WHAT COLOR? key on Jack's keyboard are yellow, red, and green from left to right.

This report presents, to our knowledge, the first instance of such symbolic communication between nonprimates—two White Carneaux pigeons *(Columba livia domestica)*. Pigeons are known to communicate under natural conditions by using coos, short grunts, and wing claps (*2*). We present here data showing that their natural inclination to communicate can be enhanced through learning and, in particular, that they are able to transmit information to one another by using symbols.

The communication system was similar to that of Savage-Rumbaugh *et al.* (*1*). The pigeons expressed words or short

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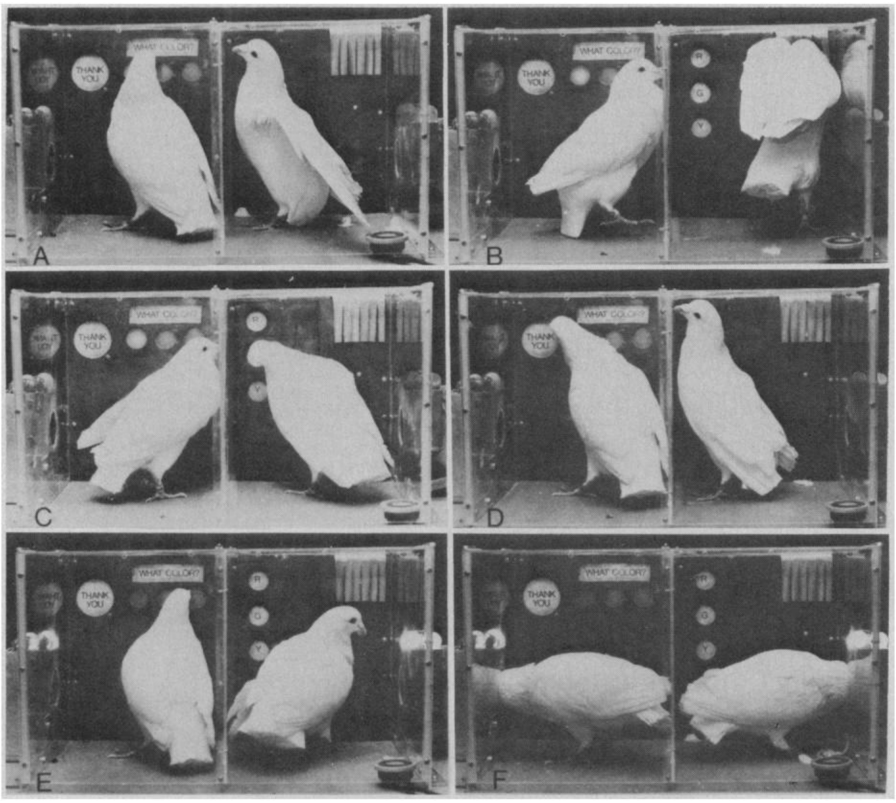

Fig. 2. Typical communication sequence. (A) Jack (left) asks Jill (right) for a color name by depressing the WHAT COLOR? key. (B) Jill looks through the curtain at the hidden color. (C) Jill selects the symbolic name for the color while Jack watches. (D) Jack rewards Jill with food by depressing the THANK YOU key. (E) Jack selects the correct color as Jill moves toward her reward. (F) Jack is rewarded with food.

phrases by depressing keys embossed with English letters or letters arranged to form words. Depressing a key illuminated it, affording both birds a clear view of the chosen symbol. The keys were arranged on adjoining keyboards (Fig. 1) in a two-bird chamber 49 cm wide by 30 cm deep by 29 cm high. The front, top, and sides of the chamber were Plexiglas, and a Plexiglas partition in the center gave each bird a clear view of the other bird and its keyboard. Electromechanical feeders at the base of each of the side walls could be operated separately to give each bird access to mixed grain. A white noise source in one corner of the chamber partially masked extraneous sounds, but no other precautions were taken to shield the subjects from the visual and auditory distractions of the laboratory room. Events in the experiment were controlled and recorded by electromechanical equipment.

The subjects were two moderately hungry adult pigeons named Jack and Jill (*3*). Each had had previous experience as a laboratory subject, but neither had been used before in procedures related to language or communication. Jack was the observer throughout the study, and Jill the informer. Each was trained separately for 5 weeks in daily sessions 1 to 3 hours in length before their communication ability was tested.

The animals were first taught to relate symbolic names to colors. Jill was taught to name three colors in response to the keyboard-imposed queston "What color?" Jack was taught, conversely, to select the color corresponding to a designated name. When the pigeons were correct, they were rewarded with grain; when incorrect, all chamber lights were extinguished for several seconds. Both subjects learned to relate the colors and symbolic names with greater than 90 percent accuracy during the first 3 weeks of training.

After Jill, the informer, had reached this level of accuracy, she was taught to search for a color that was hidden from view. This was accomplished first by moving the colored lights progressively deeper into a recess in the upper right-hand corner of her keyboard (Fig. 1) until they were 5 cm behind the surface. Jill learned to look at a color by inserting her head into the recess. The recess was then gradually covered by a curtain of gray, opaque vinyl until the colors were entirely hidden. (These precautions were taken to prevent Jack, the observer, from seeing the colors.) Jill learned to thrust her head through slits in the curtain to look at the hidden colors. She continued to name the colors with nearly 100 percent accuracy during this period.

After Jack had demonstrated his competence in decoding symbols into colors, he was taught to ask for symbols by depressing the WHAT COLOR? key. Finally, he was taught that after having been given a symbol, he should reward the informer with food before attempting to decode the symbol. He accomplished this by depressing the THANK YOU key, thus illuminating the key and operating Jill's feeder. Decoding accuracy declined during this stage but reached better than 90 percent in 5 days of training. The subjects practiced their individual assignments for several sessions before the first interanimal test.

During the first interanimal test, greater-than-chance symbolic communication was achieved (*4*). However, since neither bird had ever worked with the other before, each was somewhat distracted by the other's presence. To remedy this, we housed the subjects together continuously in the experimental chamber. After 5 days, both pigeons were responding accurately and efficiently on more than 90 percent of the trials.

The final performance was a sustained and natural conversation (Fig. 2). Jack initiated it by asking Jill for information about the hidden color. In response, Jill looked at the color behind the curtain and then depressed the key with the symbolic name for that color, illuminating the symbol. Having seen Jill accomplish this, Jack depressed the THANK YOU key, rewarding Jill with food. Then Jack looked closely at the illuminated symbol, decoded it, and selected the appropriate color on his panel, after which the equipment automatically rewarded him with food. Typically without hesitation, Jack then requested another color name (*5*). Errors were infrequent, and both subjects were highly attentive and cooperative. If one delayed in depressing a key, the other often vigorously pecked at the restraining partition.

To guarantee that the communication depended on the symbols, a control session was conducted in which the symbol keys on Jill's keyboard were covered. She proved unable to convey to Jack information about the hidden colors through any gestures or sounds. Jack's accuracy in selecting colors dropped to 30 percent for the 135 trials in this session.

There are a number of procedural differences between this study and that of

Savage-Rumbaugh *et al.* (*1*). First, taking into account the fact that the brain of the pigeon is smaller than that of the chimpanzee, and not wishing to tax the relatively limited information-processing capacity of our subjects, we used 3 rather than 11 stimulus objects. Second, we did not attempt to reverse the informer and observer roles. (We believe that this can be done but is not essential to the demonstration of interanimal communication.) Third, we used colors rather than foods as the stimulus objects to avoid the possibility that our subjects would fail to "distinguish between the use of a food name as its name and the use of that name as a request for food" (*1*). Fourth, events in all interanimal test sessions in our experiment were controlled by electromechanical equipment, eliminating possible experimenter cuing effects and the need for "experimenter-blind" conditions. Fifth, our observer could not simply duplicate the symbol provided by the informer but instead had to decode the symbol into its referent. Sixth, we did not vary the position of our symbols. (Position was no doubt significant to our subjects, just as the position of letters and figures in mathematical notation is significant to mathematicians.) Seventh, every conversation in our experiment was initiated by the observer's spontaneous request for information. Finally, the observer sustained the informer's cooperation by thanking her with a food reward for supplying information.

We have thus demonstrated that pigeons can learn to engage in a sustained and natural conversation without human intervention, and that one pigeon can transmit information to another entirely through the use of symbols.

It has not escaped our notice that an alternative account of this exchange may be given in terms of the prevailing contingencies of reinforcement. Jack "initiated the conversation" by pecking the WHAT COLOR? key because a peck at that key had illuminated it and because this illumination had been reliably followed by the illumination of one of the symbol keys. This was, in turn, the occasion upon which a peck at the THANK YOU key, followed by a peck at a corresponding color key, had produced reinforcement. Jill responded to Jack's "request for information" because the illumination of the WHAT COLOR? key was the occasion upon which looking at the hidden color and then pecking a corresponding symbol key had been reinforced. The performances were established through standard fading, shaping, chaining, and discrimination procedures (*6*-*9*). A similar account may be given of the Rumbaugh procedure (*10*), as well as of comparable human language (*11*).

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4. If the birds had responded at random to the symbol and color keys, they would have been correct on only about 11 percent of the trials. They responded correctly on more than 50 percent of the trials of the first interanimal test.
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Sun Compensation by Bees

Abstract. *In both their navigation and dance communication, bees are able to compensate for the sun's movement. When foragers are prevented from seeing the sun for 2 hours, they compensate by extrapolation, using the sun's rate of movement when last observed. These and other data suggest a time-averaging processing strategy in honey bee orientation.*

When a forager bee returns to the hive from a good source of food, she performs a dance which specifies the location of the food. On the usual vertical comb in a dark hive, she converts the direction of the food source with respect to the sun's azimuth into a dance angle with respect to vertical (*1*). Recruits decode the dance and use the direction information to find the food (*1*, *2*; *3*, p. 149). As such, the sun is the primary reference cue for honey bees. The sun, however, moves, and so is a problematical landmark for the many species that use it for navigation. The sun's exact rate of movement in azimuth depends in a complicated way on the date, time of day, and latitude. For example, at the summer solstice the rate increases by a factor of 6 from dawn to midday, changing most rapidly just before and after noon (Fig. 1). For the dance communication system to work, and even for foragers to find their way back home, animals must compensate for the sun's movement. Honey bees appear to accomplish this task by means of a time-averaged extrapolation.

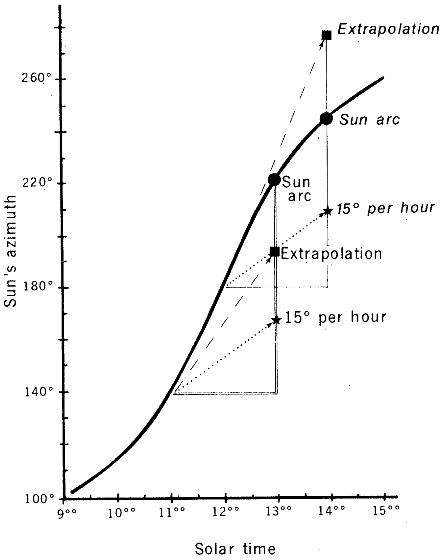

Fig. 1. The sun's azimuth movement at 40°N near the summer solstice is plotted along with the predictions of three compensation hypotheses for both a morning experiment (11 a.m. closing and 1 p.m. opening) and a noon experiment (noon closing and 2 p.m. opening). The sun's rate of azimuth movement changes quickly at this time of year. For example, at dawn the rate is 7.5° per hour, while near noon it is 44° per hour.

The first direct evidence for compensation came from bees that danced for extended periods in the hive without leaving. Frisch noticed that the dance angle slowly shifted counterclockwise (*3*, p. 347), reflecting the clockwise movement of the sun (and hence, the counterclockwise relative motion of the stationary food source with respect to the sun). Later Meder (*4*) convincingly demonstrated compensation during foraging. We now know this ability to be

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