ina, for an object at infinity. In this plane, focused images from each pupillary slit are superimposed, but then diverge as they continue past the image plane to the retinal plane, forming two retinal images. At a viewing distance of 1 m, the two retinal images of our 24-cm square targets will overlap by approximately 71 percent, producing blur over the major portion of the combined image. The overlap decreases to approximately 25 percent at 2.5 m, confining the blur to a small, central portion of the combined image and allowing greater opportunity for resolution of individual bars of the grating targets. Completely separated images will occur at a viewing distance of approximately 3.3 m, suggesting that daylight aerial resolution might be further improved at this increased viewing distance.

In water, refractive error is absent or nearly absent (1, 2). However, since fine accommodation is lacking, the image will lie on the retina at only one viewing distance. Assuming from our results that this distance is 1 m, although it could be less, then at greater viewing distances the image plane will move progressively forward of the retina. Our calculations indicate that at infinity the image plane lies approximately 1 mm in front of the retina, so that, in contrast to the aerial situation, at viewing distances beyond 1 m there is little room for divergence of the images from each slit before they strike the retina. Nevertheless, slightly increased displacements of the images on the retina will occur with increased viewing distances beyond 1 m, yielding increasing blur of the image. The double-slit model thus accounts for the observed poorer resolution with increased viewing distance in water and also for the improved resolution with increased viewing distance in air.

The double-slit pupil of the dolphin sacrifices the constant acuity over distance obtainable with a single, centrally located pupillary slit, like that observed in pinniped species (11). However, the double slit yields a considerably brighter image (in the image plane) than does the single slit, and also yields a wider field of view (13). This seems a favorable compromise adaptation for the bottlenosed dolphin, which can rely on echolocation in water to detect distant objects, and which encounters relatively few nearby objects of interest in air in the open aquatic environment.

Since the double-slit effect disappears as the pupil dilates, aerial acuity should decrease rapidly with lowered levels of illumination, because of the increased optical role of the cornea. In water, the eye is emmetropic at favorable viewing distances, even with the pupil dilated (1). Resolution losses with decreasing illumination should therefore occur much less rapidly in water.

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than in air, as with pinnipeds (11). Considerably reduced underwater resolution in very dim illumination has been found for *Tursiops* (15), but systematic comparisons of aerial and underwater acuity under various levels of illumination are not available.

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5. Transmissibility of the naturally filtered seawater, measured daily with a Hydro Products 612S transmissometer having a tube with a 1-m pathlength, ranged from 49 to 80 percent (mean, 65 percent), depending on the algal growth between weekly tank cleanings. The lower value yields an underwater visibility range for humans of roughly 5 m, and the upper limit roughly 8.5 m. Underwater performance of the animal was not significantly correlated with the different transmissibility values.
6. Incident light measurements in air and water were made daily using a Clairex 705L photocell with translucent diffuser, located at the position of an exposed grating target. Current readings from the photocell were calibrated in daylight with a United Detector Technology-40A optometer.
7. Michelson contrast, the preferred measure for grating targets, was 0.33. It was measured as $(L_{max} - L_{min})/(L_{max} + L_{min})$, where L_{max} was the luminance of a white bar and L_{min} the luminance of a dark bar of a grating target.
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Purposive Behavior as a Basis for Objective Communication Between Chimpanzees

Abstract. *The rate at which a chimpanzee approaches a hidden, distant goal varies according to social conditions and according to whether the goal is a novel object or food. This behavior furnishes a social group with sufficient information for simultaneous and successive discriminations between leaders and between goals.*

It is often assumed that without a symbolic code of vocalizations, manual gestures, or other displays which "stand for" particular objects and relations, primates are incapable of communicating about things that are not present to the senses (1). Consider, however, any molar behavior, for example, locomotion (2–5). To most human observers, walking seems purposive, that is, it appears to have some external referent. Walking is syntactic, or possesses global organization. It is informative; for example, its velocity and acceleration suggest to us how interested an animal is in his goal, and consistency of direction suggests to us where the goal might be located. There can also be considerable displacement between this "signal" and its "referent"; the signaler's behavior can be highly devious and subject to learning, hence arbitrary and noniconic; and finer details of the animal's behavior can supplement or qualify the information available

from locomotion and reduce our uncertainty about the environment still further. In short, locomotion can, if one so chooses, be said to possess most if not all of the major logical "design features" by which Hockett and Altmann (6) have tried to characterize language; and the ability of nonverbal animals to "tell" each other the precise nature and location of their goals is limited only by the richness of the signaler's purposive movements and the receiver's knowledge of the signaler and the environment in which he is operating.

In this report we extend our previous studies of inter-chimpanzee communication (3–5) and show that: (i) A chimpanzee leader's rate of locomotion provides the rest of his group with a sufficient basis for simultaneous and successive discriminations between novel toys and food, which are both highly preferred classes of objects. (ii) This result cannot be fully predicted

from the leader's behavior toward the same classes of objects when he is alone. The leader is dependent upon feedback from his group and vice versa, and in this sense communication is two-way if not intentional (7).

Two male and four female preadolescent wild-born chimpanzees, 5 to 7 years old, were tested in the 30.5 by 122 m outdoor enclosure in which they had lived for more than a year. They had had extensive previous experience on similar delayed response experiments, and effective leadership behavior was observed even on the first day of these experiments (3).

While all animals were locked in a set of small cages on the periphery of the outdoor enclosure and could not see what was going on, an experimenter entered the enclosure and carefully hid one or more novel toys (a different one on each trial) or piles of six small pieces of fruit 15 to 65 m from the release cages. The X-Y coordinates of the locations of the caches were selected from a table of random permutations and were different on every trial (8). Then one of four animals—Belle, Bandit, Bido, or Gigi—was taken from the release cage, carried to the cache, shown the goal object, and returned to a release cage. This individual will be referred to as the leader for that trial. Two animals, Shadow and Polly, were not tested as leaders because they struggled and screamed when taken more than a short distance from their companions.

In experiment 1, after a single leader was shown a single goal and returned to the release cage, the experimenter left the enclosure and ascended an observation tower and (about 2 minutes after the leader had been given the cue) pulled a cable that opened the release cage doors. The group's behavior was recorded for a minimum of 5 minutes. We gave each leader one trial a day for 22 days (11 with each class of object, toy or food).

In experiment 2 two goal objects instead of one were hidden on each trial and were located equidistant from the release cage and separated by an angle of at least 90° from the door of the release cage. One leader was shown one object and returned to the release cage and then the other leader was shown the other object and also returned to the release cage, after which the procedure was the same as in experiment 1. All six pairings of the four leaders were tested, and on a given trial each leader might see either a novel toy or food: the possible combinations generated 24 different conditions, including those on which both animals saw the same class of object. The 24 conditions were presented in random balanced orders, and we similarly varied which leader would be shown his goal first and whose goal was on the left or the

Table 1. Experiment 2: Number of trials in which the group majority went first to a given class of goal that had been shown to a given leader, rather than to another goal shown to another leader. In the case of ties, each leader was given ½ point.

Losses	Wins								Total losses
	Bido		Belle		Bandit		Gigi		
	Toy	Food	Toy	Food	Toy	Food	Toy	Food	
Bido									
Toy	–	–	2	3.5	1.5	4	1	2	14
Food	–	–	0	0.5	0.5	2	0	0.5	3.5
Belle									
Toy	2	4	–	–	4	4	0	2.5	16.5
Food	0.5	3.5	–	–	0	1	0	1	6
Bandit									
Toy	2.5	3.5	0	4	–	–	0	1	11
Food	0	2	0	3	–	–	1	0	6
Gigi									
Toy	3	4	4	4	4	3	–	–	22
Food	2	3.5	1.5	3	3	4	–	–	17
Total wins	10	20.5	7.5	18	13	18	2	7	96
Percent wins	42	85	31	75	54	75	8	29	

right. Altogether, 96 trials were conducted, four per test condition.

The procedure for experiment 3 was the same as that for experiment 1, except that instead of all of the chimpanzees being released simultaneously, the leader was held in a separate release cage and turned loose alone for 2½ minutes, and then the rest of the group was also turned loose.

Recording of behavior was analogous to snapshot photography. An electrical timer produced a click every 30 seconds, and as each click sounded we indicated on a map where each individual was located. In addition we made written notes on the animals' social interactions and on who got a share of the food or who had the novel object. A few sessions were filmed with a Bolex 16-mm movie camera.

All four animals functioned as effective leaders of travel, and in this sense there

was "interchangeability" of individuals in communication. Except on the few trials in which a leader failed to move out, the group either marched as a cohesive unit to a single hidden goal or (in experiment 2) they split into two parties, each led by one animal, and headed to both goals simultaneously. And except when one leader temporarily abandoned his own goal in experiment 2 to accompany the other leader, his path and that of his followers was usually within 10° of a direct line to his goal. Therefore, for purposes of simplifying the analysis we rescored each animal on a particular trial as either going to one goal or the other, or failing to run.

Consider next the detailed results of experiment 2. Table 1 summarizes the major data of experiment 2 in terms of in how many trials the group majority went first to a given leader's goal object on a given
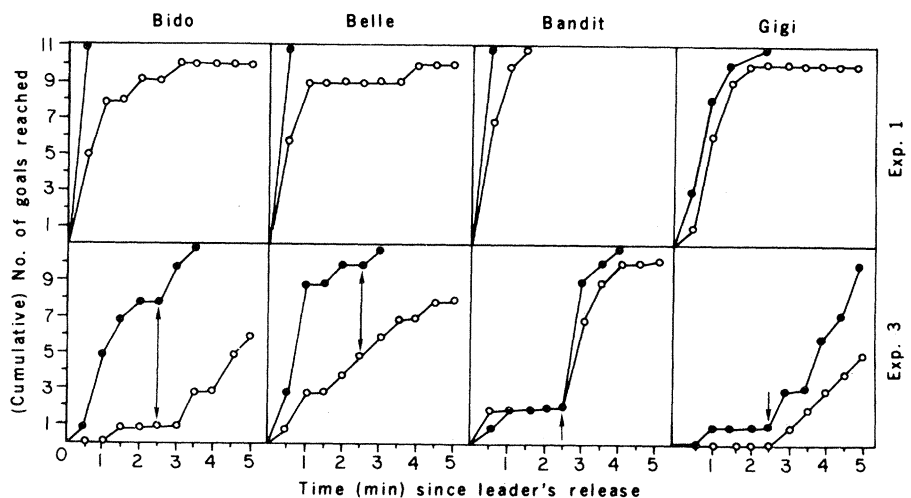

Fig. 1. Each leader's rate of locomotion to novel toys and to food. In experiment 1 (upper panels) all group members, including the leader, were released at the outset of a trial; in experiment 3 (lower panels) the leader was released first and given 2½ minutes to get the goal for himself. The arrows in the lower panels indicate the time at which the followers were released. Closed circles, food; open circles, novel object.

condition. It may be seen that group behavior was determined both by the leaders (that is, there was a leadership hierarchy) and by the goal objects. These data were subjected to analysis of variance (4 leaders × 2 classes of goal objects × 4 complete replications of all conditions) and the first two effects were significant beyond the .05 level. Results were stable over the four replications: Kendall's coefficient of concordance was .77 ($P < .001$).

From the standpoint of object communication, the crucial trials in experiment 2 are the 48 trials on which one animal was shown food and the other was shown a novel object. Here there were 38 trials on which not only the leader but also the group majority proceeded first to the food, seven trials on which they proceeded to the toy, and three trials with a tied score ($P < .001$ by sign test). All seven failures of the group majority to go first to the food involved the least preferred leader, Gigi. Gigi's relative unpopularity is not hard to explain: she was the newest and biggest member of the group, and in these tests, as under routine conditions, she shared her food only with Polly (whom, incidentally, she actively tried to recruit as a follower). The other leaders shared their food fairly readily with all.

Usually each leader took a few steps toward the goal object that we had shown him (or her) earlier, and then stopped and looked back at the rest of the group. If the other leader was setting out or trying to recruit followers more vigorously than he (which usually occurred if the goal was a more highly preferred one), he often abandoned his own goal, accompanied the other leader, and then later led the group to the second goal. The leaders split from each other on 20 of 24 trials if both had been shown food, 9 of 24 trials if both had seen novel toys, and 21 of 48 trials if one had seen food and the other had seen a novel object. The first two figures are not greatly different from those obtained in earlier experiments in which two foods or two toys were visible to all animals at the time of response (4).

The data for individual animals would lead to the same conclusions as the group majority data of Table 1. Also, on 93 percent of all trials excluding those involving ties, whichever object attracted the largest number of animals was also the object that was eventually reached in the least amount of time. It made no difference which leader had been shown his object first.

Experiment 2 of course involves a simultaneous choice or "relative" discrimination, and experiments 1 and 3 involve successive or "absolute" discrimination of leaders and goal objects. How well can we predict the former type of data from the latter? The number of trials on which a giv-

en leader reached a given class of goal in less than 30 seconds in experiment 1 correlated very highly (Pearson's $r = .97$, $N = 8$ conditions, $P < .01$) with the group majority choice data of experiment 2. In other words, whichever member of the group characteristically got the most immediate reaction from his followers when he commenced to move out (that is, when the group had a single goal) was also likely to carry the group majority, if not the whole group, in cases where he had to compete with another leader of travel. However, it would be more accurate to speak here of a hierarchy of leadership behaviors rather than a hierarchy of individuals as such, for a given individual's "rank" varied with social conditions and with goals.

The next question is how well the data of both experiment 1 and experiment 2 could be predicted from the behavior of the leader when he was alone and could get all the food for himself (experiment 3, first $2\frac{1}{2}$ minutes). The answer is, not very well; Pearson's $r = .69$ and .62, respectively, and $P > .05$ when the dependent variable for experiment 3 is the number of goals reached within $2\frac{1}{2}$ minutes, and similar results would be obtained with other measures. A much better predictor is the number of trials in experiment 3 on which the leader reached the goal object within 30 seconds after the rest of the group had also been released ($r = .96$ and .90 with experiments 1 and 2, respectively; $P < .01$).

From the foregoing it is apparent that the chimpanzees discriminated the two classes of objects when these were presented one at a time on successive trials (experiments 1 and 3), as well as when they were presented simultaneously (experiment 2). Figure 1 shows the data of experiments 1 and 3 in such a way as to graphically illustrate both successive discrimination and the dependence of each leader's running speed upon his being followed by others.

Probably because the animals had already had considerable previous practice in the test situation, manual gesturing, vocalizations, and other such signals were seldom observed in the present experiments. We do not doubt that these signals might supplement the information available from purposive locomotion and thus

further reduce a fellow chimpanzee's uncertainty about the environment. Also, we stress the fact that our data show only that purposive locomotion is a sufficient (not a necessary) cue. Indeed, in chimpanzees as well as in man one of the most impressive facts of all is the ability to get across the same general message by any number of alternative means. Whether or not interchimpanzee communication can be meaningfully compared with human language depends upon the point of view of the observer, but in our opinion the most fundamental similarities lie not in motor patterns or in linguistic considerations but at the level of perceptual and cognitive organization (2, 9).

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Osmotic Power Plants

In his recent report (1) Norman concluded that, although salination of freshwater by seawater is technically feasible as a source of energy, it is uneconomical at present because the cost of the power, 20¢ per kilowatt-hour, is too high. As shown below, this statement may be corroborated

in another way by consideration of capital costs and their amortization. However, it can also be shown that salination by a much saltier body such as the Dead Sea or the Great Salt Lake *should* be economical by the same criterion.

Case 1: Salination by seawater. First let